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Empirical Yield Tables for Minnesota

Jerold T. Hahn and Gerhard K. Raile

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EMPIRICAL YIELD TABLES FOR MINNESOTA

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Empirical yield tables are useful to forest resource managers, timber managers, wild-life managers, and multi-resource managers who are interested in estimates of current commercial forest species composition and volume or in rough, short-term projections of future conditions. Examples showing each of these uses are presented in this paper. A similar set of tables is presented in "Empirical Yield Tables for Wisconsin" (Essex and Hahn 1976) and can be used by persons interested in comparisons between States. In addition we are aware of unpublished empirical yield tables for Missouri and Iowa based on the most recent forest surveys of those States.

Presented here are yield tables compiled from data gathered on 8,807 commercial forest land plots established during the 1977 inventory of Minnesota's four Forest Survey Units (fig. 1). Tables for the entire State and for each Survey Unit were compiled by forest type and site index class. Only tables having sufficient data, usually 3 or 4 plots in each of three adjacent age classes, are presented; we feel that less than this amount of information would not be useful.

The tables give the estimated merchantable cubic foot volume yield per acre from growing-stock trees and the average basal area per acre of all live trees by stand age class for the 14 forest types defined in the Appendix. These tables provide a detailed picture of stand composition as measured by growing-stock volume.

The tables were constructed by classifying the commercial forest land plots measured in the 1977 inventory by forest type, stand age, and site index class. Then the per-acre merchantable cubic foot volume was tabulated by species group. The merchantable volume standards used are minimum 5-inch d.b.h. to a 4-inch top diameter. Individual tree volumes were computed using a formula developed from "Composite volume tables for timber and their application in the Lake States" (Gevorkiantz and Olsen 1955, Raile 1981). A full explanation of the survey procedures and definitions can be obtained from "Forest statistics for Minnesota 1977" (Jakes 1980).

The tables can be used in several ways:

1. They can be used to estimate future timber yield, in the manner of normal yield tables, where it is assumed that the volume shown in one age class will increase in 10 years to the volume shown in the next older age class. For example, from table 9 stands aged 51-60 years average 2,025 cubic feet per acre. If you have a stand of red pine 41-50 years old, you could expect that in 10 years it would approximate this volume.

2. These tables, in conjunction with other forest inventory publications, can also be used to compare volume estimates for progressive rotation ages. For example, the aspen type occupied 5,302,000 acres in Minnesota in 1977 (Jakes 1980). For a selected rotation and an equal number of acres harvested each year the annual harvest volume estimates can be derived as follows using the yields shown in table 50:

Rotation age (years)	**Area harvested**[1] (thousand acres)		**Merchantable volume/acre**[2] (cubic feet)		**Annual harvest volume/year** (million cubic feet)
35	151.5	×	930	=	140.9
45	117.8	×	1,122	=	132.2
55	96.4	×	1,201	=	115.8

In addition these volumes can be broken down by species group. (See Appendix for a detailed species

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[1] *5,302,000 acres/35 years = 151,500 acres/year.*
[2] *From table 50.*

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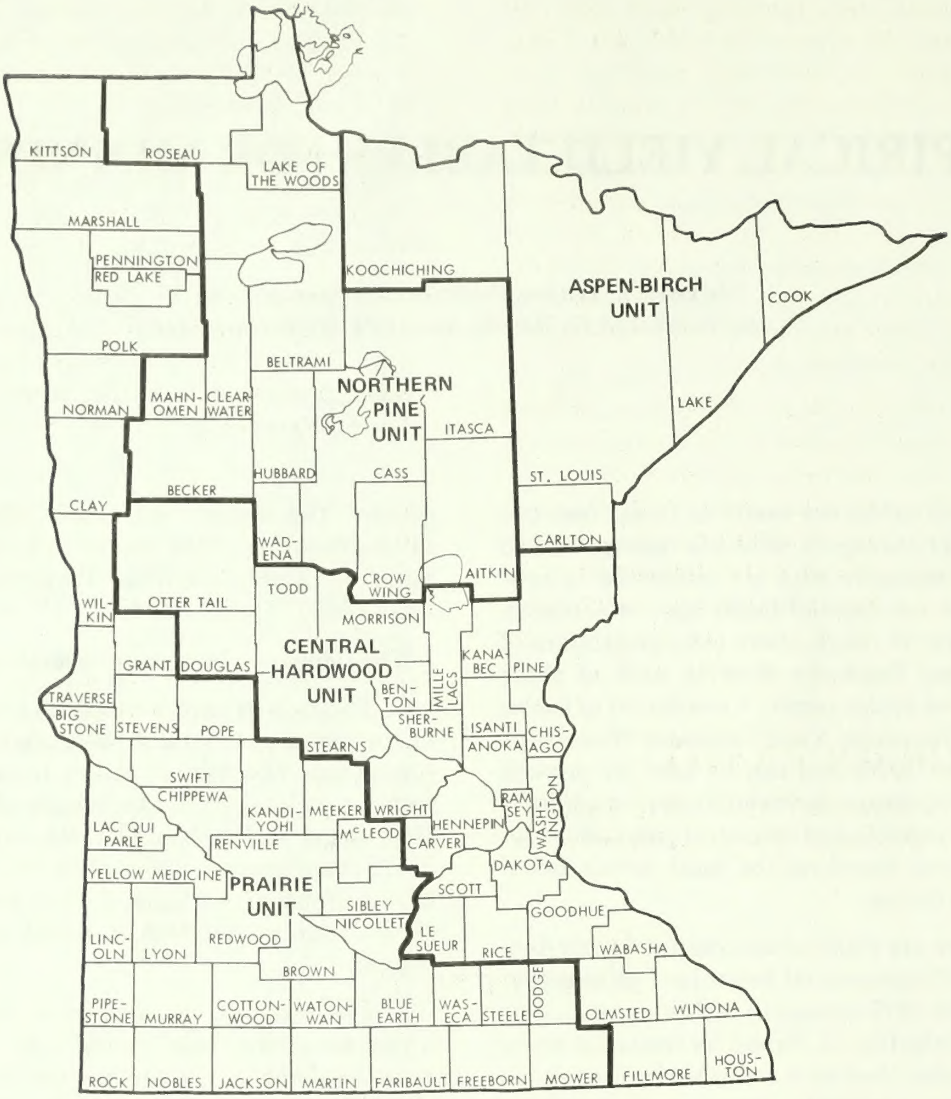

Figure 1. — *Forest survey units in Minnesota.*

breakdown of the species group.) In the above three rotations for example:

Rotation age (years)	Harvest volume	Softwood[3]	Hardwood
	- - - - - - - -(million cubic feet)- - - - - - - -		
35	140.9	15.9	125.0
45	132.2	15.1	117.1
55	115.8	14.7	101.1

According to this analysis, both the greatest total yield and the greatest softwood yield would be attained by using a 35-year rotation for the aspen type, although more acres would have to be harvested each year to obtain that volume. Currently, more than half the plots in the aspen type are in stands older than 35 years. Therefore, some volume from older plots would have to be harvested to reach a 35-year rotation.

3. Finally the basal area values in these tables allow a comparison between stand density and stand age that can be used to determine whether existing stands are fully stocked. For example, in 1977 there were 923 acres of aspen 51 to 60 years old in the 61- to 70-site index class in Minnesota (Jakes 1980). Yields in these stands (all species) averaged 1,214 cubic feet

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[3] *From table 50. 105 cubic feet/ac × 51,500 acres = 15,900,000 cubic feet.*

per acre, and basal areas (growing stock and cull combined) averaged 94 square feet (table 46). Thus, the ratio of volume to basal area was 12.9 to 1. Schlaegel (1971) predicted that such a ratio for fully stocked stands of aspen in Minnesota would be 26 to 1. If we view Schlaegel's prediction as an index of stand potential we can generalize that similar aspen sites that are fully stocked could be expected to yield roughly twice as much as these stands are producing now. The comparison can only be approximate as Schlaegel used different standards of merchantability in computing his volumes.

The volumes shown in these tables were obtained from plots that ranged from stands in an undisturbed state to stands that had been cut repeatedly. Thus standard errors of mean volume are given in the tables to indicate this variation. Sampling errors in percent can be determined by dividing the standard error by the mean volume; for example, the sampling error for jack pine in the 41- to 50-year age class all sites combined (table 5) is + 5.7 percent ((73/1,272) × 100).

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APPENDIX

FOREST TYPE DEFINITIONS

A classification of forest land based upon the species forming a plurality of live-tree stocking. Major forest types in Minnesota are:

Jack pine. — Forests in which jack pine comprises a plurality of the stocking. (Common associates include eastern white pine, red pine, aspen, birch, and maple.)

Red pine. — Forests in which red pine comprises a plurality of the stocking. (Common associates include eastern white pine, jack pine, aspen, birch, and maple.)

White pine. — Forests in which eastern white pine comprises a plurality of the stocking. (Common associates include red pine, jack pine, aspen, birch, and maple.)

Balsam fir. — Forests in which balsam fir comprises a plurality of stocking. (Common associates include white spruce, aspen, maple, birch, northern white-cedar, and tamarack.)

White spruce. — Forests in which white spruce comprises a plurality of the stocking. (Common associates include balsam fir, aspen, maple, birch, northern white-cedar, tamarack.)

Black spruce. — Forests in which black spruce comprises a plurality of the stocking. (Common associates include tamarack and northern white-cedar.)

Northern white-cedar. — Forests in which northern white-cedar comprises a plurality of the stocking. (Common associates include tamarack and black spruce.)

Tamarack. — Forests in which tamarack comprises a plurality of the stocking. (Common associates include black spruce and northern white-cedar.)

Oak. — Forests in which northern red oak, white oak, or bur oak, singly or in combination, comprise a plurality of the stocking. (Common associates include elm, maple, and aspen.)

Elm-ash-cottonwood. — Forests in which lowland elm, ash, cottonwood and red maple, singly or in combination, comprise a plurality of the stocking. (Common associates include basswood and balsam poplar.)

Maple-basswood. — Forests in which sugar maple, basswood, yellow birch, upland American elm, and red maple, singly or in combination, comprise a plurality of the stocking. (Common associates include white pine, and elm.)

Aspen. — Forests in which quaking aspen or bigtooth aspen, singly or in combination, comprise a plurality of the stocking. (Common associates include balsam poplar, balsam fir, and paper birch.)

Paper birch. — Forests in which paper birch comprises a plurality of the stocking. (Common associates include maple, aspen, and balsam fir.)

Balsam poplar. — Forests in which balsam poplar comprises a plurality of the stocking. (Common associates include aspen, elm, and ash.)

PRINCIPAL TREE SPECIES GROUPS IN MINNESOTA[4]

Softwoods:	
Eastern white pine	*Pinus strobus*
Red pine	*Pinus resinosa*
Jack pine	*Pinus banksiana*
White spruce	*Picea glauca*
Black spruce	*Picea mariana*
Balsam fir	*Abies balsamea*
Tamarack	*Larix laricina*
Northern white-cedar	*Thuja occidentalis*
Other softwoods:	
Eastern redcedar	*Juniperus virginiana*
Hardwoods:	
White oaks:	
White oak	*Quercus alba*
Bur oak	*Quercus macrocarpa*
Select red oaks:	
Northern red oak	*Quercus rubra*
Other red oak	*Quercus elipsoidalis*
Yellow birch	*Betula alleghaniensis*
Hard maples:	
Blackmaple	*Acer nigrum*
Sugar maple	*Acer saccharum*
Soft maples:	
Red maple	*Acer rubrum*
Silver maple	*Acer saccharinum*
Ashes:	
Black ash	*Fraxinus nigra*
Green ash	*Fraxinus pennsylvanica*
Balsam poplar	*Populus balsamifera*
Paper birch	*Betula papyrifera*
Bigtooth aspen	*Populus grandidentata*
Quaking aspen	*Populus tremuloides*
Basswood	*Tilia americana*
Elms:	
American elm	*Ulmus americana*
Slippery elm	*Ulmus rubra*
Rock elm	*Ulmus thomassii*
Select hardwoods:	
Butternut	*Juglans cinerea*
Black walnut	*Juglans nigra*
Black cherry	*Prunus serotina*
Other hardwoods:	
Boxelder	*Acer negundo*
Eastern cottonwood	
Populus deltoides	
Black willow	*Salix nigra*
River birch	*Betula nigra*
Hackberry	*Celtis occidentalis*

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[4] *The common and scientific names are based on: Little, Elbert L., Jr. 1953. Check list of Native and Naturalized Trees of the United States (including Alaska). U.S. Department of Agriculture, Agriculture Handbook 41, 472 p.*

Table 1.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Minnesota, 1977[1]

Jack pine forest type - Site index class 0-50

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years) 0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	19	0	8	0	0	66	2	6	0	0	209	0	0
Red pine	34	26	94	0	59	45	43	0	0	65	71	0	0
Jack pine	435	87	0	129	734	407	631	553	515	639	335	503	0
White spruce	1	0	0	0	0	0	0	0	0	0	0	29	0
Black spruce	25	0	0	0	0	0	0	23	0	457	57	272	0
Balsam fir	5	0	0	0	0	0	0	19	0	77	0	0	0
Tamarack	0	0	0	0	0	0	0	0	0	0	0	0	0
Northern white-cedar	0	0	0	0	0	0	0	0	0	0	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	518	113	102	129	793	518	676	601	515	1,238	672	804	0
Hardwoods:													
Select white oaks	2	0	0	0	0	9	0	0	0	0	0	0	0
Select red oaks	13	0	0	0	0	68	0	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Soft maple	2	0	0	0	0	0	10	0	0	0	0	0	0
Ash	0	0	0	0	0	0	0	0	0	0	0	0	0
Balsam poplar	1	0	0	0	0	4	0	0	0	0	0	0	0
Paper birch	25	0	30	0	0	60	11	15	0	142	0	88	0
Bigtooth aspen	1	0	0	0	0	4	0	0	0	0	0	0	0
Quaking aspen	38	66	9	11	7	40	21	91	0	49	0	55	0
Basswood	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	0	0	0	0	0	0	0	0	0	0	0	0	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	82	66	38	11	7	185	43	106	0	191	0	143	0
Total all species	601	179	140	140	800	702	718	707	515	1,428	672	947	0
Number of plots	51	4	4	4	4	10	10	9	2	1	1	2	0
Standard error[3]	63	67	75	58	305	114	142	162	50	R	R	163	0
Average basal area	68	33	46	56	91	69	82	65	54	128	60	90	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 2.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Minnesota, 1977[1]

Jack pine forest type - Site index class 51-60

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years) 0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	3	0	0	0	0	7	0	4	13	0	0	0	0
Red pine	53	35	12	0	61	42	62	111	102	0	0	0	0
Jack pine	985	1,101	153	373	710	814	1,318	1,455	1,349	1,479	651	0	0
White spruce	6	0	0	0	0	13	8	0	29	0	0	0	0
Black spruce	30	0	0	6	0	23	7	120	0	135	314	0	0
Balsam fir	8	0	0	0	4	10	10	5	11	71	0	0	0
Tamarack	1	0	0	0	0	3	0	0	0	0	0	0	0
Northern white-cedar	0	0	0	0	0	0	0	0	0	0	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	1,086	1,136	165	379	774	911	1,406	1,695	1,505	1,684	964	0	0
Hardwoods:													
Select white oaks	2	0	0	0	2	0	8	2	0	0	0	0	0
Select red oaks	3	0	0	0	2	3	2	4	0	0	78	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Soft maple	2	0	0	0	0	0	7	0	0	0	0	0	0
Ash	0	0	0	0	0	0	0	0	0	0	0	0	0
Balsam poplar	1	0	0	0	0	1	3	0	0	0	0	0	0
Paper birch	12	0	7	0	4	4	12	10	15	50	302	0	0
Bigtooth aspen	1	0	0	0	0	0	0	12	0	0	0	0	0
Quaking aspen	71	0	0	21	43	101	42	221	13	0	0	0	0
Basswood	0	0	0	0	0	0	0	3	0	0	0	0	0
Elm	0	0	0	0	0	0	0	0	0	0	0	0	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	93	0	7	21	51	109	73	252	28	50	380	0	0
Total all species	1,179	1,136	172	400	826	1,020	1,479	1,947	1,533	1,734	1,344	0	0
Number of plots	125	8	5	10	15	33	31	15	4	2	2	0	0
Standard error	79	407	60	72	58	96	158	346	273	158	217	0	0
Average basal area	83	58	30	62	83	80	94	103	102	122	81	0	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

Table 3.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Minnesota, 1977[1]

Jack pine forest type - Site index class 61-70

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	4	0	0	5	0	10	0	0	0	0	0	0	0
Red pine	71	0	45	67	97	60	85	49	0	0	0	0	0
Jack pine	1,015	273	70	559	875	1,226	1,163	1,548	0	968	0	0	0
White spruce	5	0	0	0	14	4	3	0	0	0	0	0	0
Black spruce	25	0	0	8	20	30	48	0	0	0	0	0	0
Balsam fir	17	0	65	49	28	5	8	0	0	0	0	0	0
Tamarack	0	0	0	0	0	0	0	0	0	0	0	0	0
Northern white-cedar	0	0	0	0	0	0	0	0	0	0	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	1,137	273	180	687	1,034	1,335	1,308	1,597	0	968	0	0	0
Hardwoods													
Select white oaks	3	0	0	0	0	8	3	0	0	0	0	0	0
Select red oaks	6	40	0	24	0	0	10	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Soft maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	1	0	0	0	0	2	0	0	0	0	0	0	0
Balsam poplar	2	0	0	0	0	0	8	0	0	0	0	0	0
Paper birch	32	12	119	8	21	27	56	42	0	0	0	0	0
Bigtooth aspen	12	0	0	0	12	9	27	0	0	0	0	0	0
Quaking aspen	64	33	0	21	43	58	102	25	0	713	0	0	0
Basswood	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	1	0	0	1	0	0	3	0	0	0	0	0	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	2	0	0	0	0	0	8	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	122	86	119	54	76	103	216	67	0	713	0	0	0
Total all species	1,259	359	298	741	1,110	1,438	1,524	1,664	0	1,681	0	0	0
Number of plots	89	3	2	10	20	28	20	5	0	1	0	0	0
Standard error[3]	63	156	120	130	88	100	133	281	0	R	0	0	0
Average basal area	89	40	45	84	88	95	94	103	0	110	0	0	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 4.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Minnesota, 1977[1]

Jack pine forest type - Site index class 71-80

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)										
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:												
White pine	3	0	0		7	0	0	0	0	0	0	0	0
Red pine	113	0	0	101	65	206	42	114	0	0	0	0	0
Jack pine	1,074	561	114	832	769	1,477	943	1,970	0	0	0	0	0
White spruce	3	0	0	0	6	4	0	0	0	0	0	0	0
Black spruce	53	0	0	0	89	62	0	0	0	0	0	0	0
Balsam fir	19	0	0	17	3	17	0	140	0	0	0	0	0
Tamarack	0	0	0	0	0	0	0	0	0	0	0	0	0
Northern white-cedar	0	0	0	0	0	0	0	0	0	0	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	1,265	561	114	950	937	1,766	985	2,224	0	0	0	0	0
Hardwoods:												
Select white oaks	3	0	0	0	7	0	0	0	0	0	0	0	0
Select red oaks	8	0	0	31	14	0	0	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Soft maple	1	0	0	0	0	2	0	0	0	0	0	0	0
Ash	0	0	0	0	0	0	0	0	0	0	0	0	0
Balsam poplar	4	0	0	0	0	0	0	46	0	0	0	0	0
Paper birch	30	0	0	41	48	17	0	39	0	0	0	0	0
Bigtooth aspen	17	0	0	0	46	0	0	0	0	0	0	0	0
Quaking aspen	121	0	0	0	96	208	164	116	0	0	0	0	0
Basswood	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	0	0	0	0	0	0	0	0	0	0	0	0	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	183	0	0	72	212	227	164	201	0	0	0	0	0
Total all species	1,447	561	114	1,022	1,149	1,993	1,150	2,424	0	0	0	0	0
Number of plots	39	1	2	4	14	13	2	3	0	0	0	0	0
Standard error[3]	139	R	114	239	164	195	148	789	0	0	0	0	0
Average basal area	95	75	68	86	85	109	77	132	0	0	0	0	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 5.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Minnesota, 1977[1]

Jack pine forest type - All site index classes

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	6	0	2	2	3	14	0	4	9	0	70	0	0
Red pine	64	24	40	41	79	74	66	72	68	16	24	0	0
Jack pine	910	659	87	489	799	1,005	1,148	1,235	1,071	1,141	545	503	0
White spruce	5	0	0	0	8	7	5	0	19	0	0	29	0
Black spruce	30	0	0	5	29	28	18	61	0	182	228	272	0
Balsam fir	12	0	10	23	12	8	8	21	8	55	0	0	0
Tamarack	0	0	0	0	0	1	0	0	0	0	0	0	0
Northern white-cedar	0	0	0	0	0	0	0	0	0	0	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	1,027	682	140	559	929	1,138	1,246	1,392	1,175	1,393	867	804	0
Hardwoods:													
Select white oaks	2	0	0	0	2	4	5	1	0	0	0	0	0
Select red oaks	6	8	0	12	4	9	4	2	0	0	52	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Soft maple	1	0	0	0	1	0	5	0	0	0	0	0	0
Ash	0	0	0	0	0	1	0	0	0	0	0	0	0
Balsam poplar	2	0	0	0	0	1	4	4	0	0	0	0	0
Paper birch	23	2	30	8	29	20	25	19	10	60	201	88	0
Bigtooth aspen	6	0	0	0	17	4	9	6	0	0	0	0	0
Quaking aspen	73	23	3	15	77	96	61	140	9	190	0	55	0
Basswood	0	0	0	0	0	0	0	1	0	0	0	0	0
Elm	0	0	0	0	0	0	1	0	0	0	0	0	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	1	0	0	0	0	0	3	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	115	33	33	36	129	134	117	172	19	251	253	143	0
Total all species	1,142	715	173	595	1,059	1,272	1,362	1,564	1,193	1,644	1,120	947	0
Number of plots	311	16	13	30	57	84	63	33	6	4	3	2	0
Standard error	44	228	39	77	65	73	97	206	276	98	257	163	0
Average basal area	84	49	43	73	86	88	91	94	86	120	74	90	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

Table 6.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Minnesota, 1977[1]

Red pine forest type - Site index class 51-60

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)										
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	142	0	0	0	28	199	102	58	163	342	304	0	0
Red pine	1,086	263	80	122	870	904	679	1,122	1,935	1,125	1,249	0	0
Jack pine	111	0	30	0	364	170	353	111	42	143	0	0	0
White spruce	13	0	0	0	36	0	0	0	27	0	74	0	0
Black spruce	8	0	0	0	0	0	0	62	6	0	0	0	0
Balsam fir	44	0	12	0	0	102	46	23	19	0	362	0	0
Tamarack	4	0	0	0	0	0	0	0	16	0	0	0	0
Northern white-cedar	4	0	0	0	0	0	0	17	9	0	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	1,412	263	122	122	1,298	1,375	1,181	1,394	2,217	1,609	1,988	0	0
Hardwoods:													
Select white oaks	4	0	0	0	13	0	0	9	0	20	0	0	0
Select red oaks	10	0	0	0	16	39	0	0	6	12	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Soft maple	1	0	0	0	14	0	0	0	0	0	0	0	0
Ash	0	0	0	0	0	0	0	0	0	0	0	0	0
Balsam poplar	1	0	0	0	0	0	0	0	3	0	0	0	0
Paper birch	72	0	0	0	31	61	0	0	199	49	36	0	0
Bigtooth aspen	14	0	0	0	0	0	0	0	50	0	0	0	0
Quaking aspen	104	51	0	0	51	113	69	94	160	193	23	0	0
Basswood	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	0	0	0	0	0	0	0	0	0	0	0	0	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	206	51	0	0	124	213	69	102	419	274	59	0	0
Total all species	1,618	314	122	122	1,422	1,588	1,250	1,496	2,636	1,883	2,048	0	0
Number of plots	41	3	4	1	3	6	2	4	11	5	2	0	0
Standard error[3]	182	314	70	R	446	172	443	397	401	357	124	0	0
Average basal area	108	33	28	86	124	135	98	93	140	102	172	0	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 7.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Minnesota, 1977[1]

Red pine forest type - Site index class 61-70

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	111	0	0	0	36	108	288	33	750	161	211	0	0
Red pine	1,168	196	45	361	1,116	894	2,108	1,703	2,854	2,131	1,390	0	0
Jack pine	75	165	0	33	0	296	186	0	0	82	0	0	0
White spruce	37	0	0	61	120	0	17	0	0	0	0	0	0
Black spruce	12	0	0	0	27	41	0	0	0	89	0	0	0
Balsam fir	39	0	0	0	113	116	0	14	0	0	122	0	0
Tamarack	3	0	0	17	0	0	0	0	0	0	0	0	0
Northern white-cedar	0	0	0	0	0	0	0	0	0	0	0	0	0
Other softwoods	12	0	0	77	0	0	0	0	0	0	0	0	0
Total	1,457	361	45	549	1,412	1,455	2,599	1,751	3,603	2,464	1,723	0	0
Hardwoods:													
Select white oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Select red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Soft maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	4	0	0	0	0	0	24	0	0	0	0	0	0
Balsam poplar	16	0	0	0	0	140	27	0	0	0	0	0	0
Paper birch	16	0	0	0	38	0	31	0	0	0	83	0	0
Bigtooth aspen	8	0	0	0	12	0	0	0	0	0	131	0	0
Quaking aspen	89	0	0	27	34	152	247	14	205	396	0	0	0
Basswood	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	1	0	0	0	0	0	8	0	0	0	0	0	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	3	0	0	0	0	0	0	0	85	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	136	0	0	27	85	292	337	14	291	396	214	0	0
Total all species	1,593	361	45	576	1,497	1,748	2,936	1,765	3,894	2,860	1,937	0	0
Number of plots	25	2	2	4	5	2	4	3	1	1	1	0	0
Standard error[3]	253	361	45	284	438	61	579	708	R	R	R	0	0
Average basal area	98	29	46	62	106	113	155	94	154	146	109	0	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 8.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Minnesota, 1977[1]

Red pine forest type - Site index class 71-80

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years) 0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	108	0	0	0	0	173	0	0	532	0	0	0	0
Red pine	1,160	0	929	860	1,408	1,526	588	0	1,387	0	0	0	0
Jack pine	176	0	0	61	440	393	0	0	0	0	0	0	0
White spruce	26	0	0	21	0	29	215	0	0	0	0	0	0
Black spruce	13	0	0	58	0	0	0	0	0	0	0	0	0
Balsam fir	19	0	0	0	0	30	62	0	62	0	0	0	0
Tamarack	0	0	0	0	0	0	0	0	0	0	0	0	0
Northern white-cedar	0	0	0	0	0	0	0	0	0	0	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	1,502	0	929	999	1,849	2,152	865	0	1,980	0	0	0	0
Hardwoods:													
Select white oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Select red oaks	24	0	78	0	33	0	0	0	26	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Soft maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	0	0	0	0	0	0	0	0	0	0	0	0	0
Balsam poplar	0	0	0	0	0	0	0	0	0	0	0	0	0
Paper birch	146	0	39	0	316	22	0	0	415	0	0	0	0
Bigtooth aspen	0	0	0	0	0	0	0	0	0	0	0	0	0
Quaking aspen	130	0	0	82	177	0	320	0	296	0	0	0	0
Basswood	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	0	0	0	0	0	0	0	0	0	0	0	0	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	300	0	118	82	526	22	320	0	737	0	0	0	0
Total all species	1,802	0	1,046	1,082	2,374	2,174	1,185	0	2,717	0	0	0	0
Number of plots	13	0	2	3	3	2	1	0	2	0	0	0	0
Standard error[3]	245	0	811	271	487	126	R	0	226	0	0	0	0
Average basal area	114	0	115	112	121	122	56	0	124	0	0	0	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 9.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Minnesota, 1977[1]

Red pine forest type - All site index classes

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	118	0	0	0	24	143	170	38	268	275	220	116	0
Red pine	1,036	197	283	518	1,129	877	1,375	995	1,978	1,172	966	691	0
Jack pine	104	70	15	39	219	228	195	68	31	114	0	0	0
White spruce	22	0	0	38	64	16	36	15	19	0	30	0	0
Black spruce	8	0	0	22	12	6	0	21	5	13	0	0	0
Balsam fir	37	0	6	0	51	99	19	11	22	0	169	92	0
Tamarack	3	0	0	8	0	0	0	0	11	0	0	0	0
Northern white-cedar	2	0	0	0	0	0	0	6	6	0	0	0	0
Other softwoods	3	0	0	39	0	0	0	0	0	0	0	0	0
Total	1,334	267	305	664	1,500	1,369	1,795	1,154	2,341	1,573	1,385	899	0
Hardwoods:													
Select white oaks	2	0	0	0	4	0	0	3	0	14	0	0	0
Select red oaks	8	0	20	0	13	18	4	0	8	9	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Soft maple	0	0	0	0	4	0	0	0	0	0	0	0	0
Ash	1	0	0	0	0	0	12	0	0	0	0	0	0
Balsam poplar	5	0	0	0	0	26	13	0	3	0	0	0	0
Paper birch	60	0	10	0	112	57	16	0	201	35	60	0	0
Bigtooth aspen	8	0	0	0	6	0	0	0	37	0	26	0	0
Quaking aspen	92	26	0	44	78	82	181	41	171	195	9	212	0
Basswood	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	0	0	0	0	0	0	4	0	0	0	0	0	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	1	0	0	0	0	0	0	0	6	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	178	26	29	44	216	182	230	44	425	252	95	212	0
Total all species	1,512	292	334	709	1,716	1,551	2,025	1,197	2,766	1,826	1,480	1,110	0
Number of plots	95	6	8	8	11	13	8	12	15	7	5	2	0
Standard error	115	174	221	200	274	142	448	247	304	358	328	43	0
Average basal area	101	27	54	84	115	119	120	80	141	99	114	100	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

Table 10.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Minnesota, 1977[1]

White pine forest type - Site index class 51-60

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years) 0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	764	843	120	0	0	0	410	608	837	1,329	774	1,228	0
Red pine	113	0	163	0	0	0	158	91	0	0	14	1,350	0
Jack pine	27	0	0	0	0	0	0	125	27	0	0	0	0
White spruce	71	0	0	0	0	0	0	169	125	0	45	0	0
Black spruce	28	0	62	0	0	0	177	0	0	0	45	0	0
Balsam fir	47	0	0	0	0	0	122	0	0	71	110	0	0
Tamarack	0	0	0	0	0	0	0	0	0	0	0	0	0
Northern white-cedar	0	0	0	0	0	0	0	0	0	0	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	1,049	843	345	0	0	0	867	993	989	1,400	987	2,578	0
Hardwoods:													
Select white oaks	3	0	0	0	0	0	0	16	0	0	0	0	0
Select red oaks	11	0	0	0	0	0	0	40	0	80	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	10	0	0	0	0	0	0	0	0	0	30	0	0
Soft maple	8	0	0	0	0	0	0	0	38	0	0	0	0
Ash	0	0	0	0	0	0	0	0	0	0	0	0	0
Balsam poplar	0	0	0	0	0	0	0	0	0	0	0	0	0
Paper birch	102	0	0	0	0	0	191	114	104	161	113	55	0
Bigtooth aspen	0	0	0	0	0	0	0	0	0	0	0	0	0
Quaking aspen	90	0	0	0	0	0	0	165	175	79	59	0	0
Basswood	20	0	0	0	0	0	0	0	0	224	22	0	0
Elm	0	0	0	0	0	0	0	0	0	0	0	0	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	245	0	0	0	0	0	191	336	318	544	223	55	0
Total all species	1,294	843	345	0	0	0	1,057	1,329	1,306	1,945	1,211	2,632	0
Number of plots	18	1	1	0	0	0	1	3	4	1	6	1	0
Standard error[3]	164	R	R	0	0	0	R	356	199	R	344	R	0
Average basal area	96	120	34	0	0	0	68	81	115	98	93	153	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 11.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Minnesota, 1977[1]

White pine forest type - All site index classes

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years) 0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	714	843	60	0	517	634	1,119	659	748	678	725	1,071	0
Red pine	183	0	82	0	41	301	240	355	121	81	25	675	0
Jack pine	61	0	0	0	60	141	0	132	126	19	0	0	0
White spruce	70	0	0	0	249	0	0	105	83	0	128	0	0
Black spruce	18	0	31	0	0	0	59	0	0	24	40	0	0
Balsam fir	43	0	0	0	39	18	71	7	0	24	117	19	0
Tamarack	0	0	0	0	0	0	0	0	0	0	0	0	0
Northern white-cedar	4	0	0	0	0	0	0	0	0	0	14	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	1,094	843	173	0	905	1,094	1,489	1,258	1,078	825	1,049	1,764	0
Hardwoods:													
Select white oaks	10	0	0	0	0	8	13	49	0	0	0	0	0
Select red oaks	10	0	0	0	0	0	48	26	0	27	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	4	0	0	0	0	0	0	0	0	0	16	0	0
Soft maple	9	0	0	0	0	0	26	8	25	0	9	0	0
Ash	6	0	0	0	0	0	22	24	0	0	0	0	0
Balsam poplar	1	0	0	0	0	6	0	0	0	0	0	0	0
Paper birch	78	0	0	0	158	114	113	56	69	122	82	27	0
Bigtooth aspen	1	0	0	0	0	0	0	0	0	12	0	0	0
Quaking aspen	108	0	0	0	0	7	217	123	331	65	64	0	0
Basswood	9	0	0	0	0	0	0	0	0	75	12	0	0
Elm	0	0	0	0	0	0	0	0	0	0	0	0	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	236	0	0	0	158	136	440	286	426	300	183	27	0
Total all species	1,330	843	173	0	1,063	1,230	1,928	1,544	1,504	1,125	1,232	1,792	0
Number of plots	41	1	2	0	1	5	3	7	6	3	11	2	0
Standard error[3]	109	R	173	0	R	199	437	182	257	410	240	840	0
Average basal area	99	120	27	0	82	101	122	97	104	93	100	133	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Minnesota State Total
Black Spruce
Site Index 0-50

Table 12.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Minnesota, 1977[1]

Black spruce forest type - Site index class 0-50

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	2	0	2	1	0	3	4	1	1	6	0	0	0
Red pine	1	0	0	0	0	4	0	0	0	14	0	0	0
Jack pine	11	2	2	1	7	1	35	22	25	6	18	0	0
White spruce	4	0	1	1	4	7	6	5	10	0	13	0	0
Black spruce	328	64	132	134	164	367	411	570	541	592	653	381	918
Balsam fir	20	2	8	4	15	34	44	29	47	18	1	9	0
Tamarack	40	7	15	27	26	38	53	74	69	50	60	71	47
Northern white-cedar	11	3	0	2	9	14	12	7	29	44	0	24	28
Other softwoods	0	0	0	0	0	0	0	3	0	0	0	0	0
Total	417	78	160	169	224	468	566	710	722	729	746	485	993
Hardwoods:													
Select white oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Select red oaks	0	0	0	1	0	0	0	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Soft maple	0	0	0	0	0	0	2	0	1	0	0	0	0
Ash	2	0	0	0	0	10	0	2	4	0	1	2	0
Balsam poplar	1	0	1	0	1	1	5	0	4	2	0	0	0
Paper birch	6	0	5	1	2	6	11	9	18	15	8	0	0
Bigtooth aspen	0	0	0	1	0	0	0	1	0	1	0	0	0
Quaking aspen	22	2	22	9	15	15	68	33	33	18	15	0	0
Basswood	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	0	0	0	0	0	0	0	0	0	0	0	4	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	33	2	28	12	18	33	85	45	60	35	24	6	0
Total all species	450	80	188	182	242	501	651	755	782	764	769	491	993
Number of plots	597	21	54	118	95	60	67	45	48	40	28	12	9
Standard error	19	30	29	17	27	63	72	72	73	84	97	75	195
Average basal area	71	29	40	53	63	77	88	89	87	94	98	72	107

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

Table 13.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Minnesota, 1977[1]

Black spruce forest type - Site index class 51-60

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years) 0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	21	0	0	0	0	0	0	55	220	0	0	0	0
Red pine	6	0	0	0	0	0	0	0	92	0	0	0	0
Jack pine	28	31	46	0	0	44	102	0	0	0	0	0	0
White spruce	2	0	0	0	0	0	5	0	22	0	0	0	0
Black spruce	549	163	101	235	367	654	737	983	1,472	1,585	908	0	0
Balsam fir	35	41	14	6	32	30	64	25	95	0	136	0	0
Tamarack	30	0	36	10	52	28	0	30	140	0	0	0	0
Northern white-cedar	10	0	0	22	0	0	22	31	0	0	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	682	235	197	273	452	755	929	1,125	2,042	1,585	1,044	0	0
Hardwoods:													
Select white oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Select red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Soft maple	1	0	0	0	5	0	0	0	0	0	0	0	0
Ash	2	0	0	0	0	0	11	0	0	0	0	0	0
Balsam poplar	1	0	0	0	0	0	11	0	0	0	0	0	0
Paper birch	10	0	0	5	8	0	15	57	0	0	0	0	0
Bigtooth aspen	0	0	0	0	0	0	0	0	0	0	0	0	0
Quaking aspen	37	0	0	48	61	59	103	11	0	0	0	0	0
Basswood	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	0	0	0	0	0	0	0	0	0	0	0	0	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	51	0	0	53	74	59	141	68	0	0	0	0	0
Total all species	733	235	197	326	526	814	1,070	1,193	2,042	1,585	1,044	0	0
Number of plots	45	4	7	7	6	5	6	5	3	1	1	0	0
Standard error[3]	96	103	111	103	160	90	197	268	511	R	R	0	0
Average basal area	75	38	50	62	67	92	102	81	115	105	112	0	0

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[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 14.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Minnesota, 1977[1]

Black spruce forest type - All site index classes

(In cubic feet per acre)

Species	Average[2]	0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
		Stand-age class (years)											
Softwoods:													
White pine	3	0	2	1	0	2	4	7	14	6	0	0	0
Red pine	2	0	0	0	0	4	0	0	5	14	0	0	0
Jack pine	12	7	7	1	7	4	41	19	24	6	18	0	0
White spruce	4	0	1	1	4	6	8	5	11	0	13	0	0
Black spruce	344	80	131	140	176	395	434	614	595	616	662	381	918
Balsam fir	22	9	11	4	16	41	45	28	50	17	6	9	0
Tamarack	40	6	17	26	28	40	51	70	73	49	58	71	47
Northern white-cedar	11	2	0	3	8	13	13	9	28	43	0	24	28
Other softwoods	0	0	0	0	0	0	0	2	0	0	0	0	0
Total	438	103	169	175	239	504	595	753	800	750	756	485	993
Hardwoods:													
Select white oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Select red oaks	0	0	0	1	0	0	0	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Soft maple	0	0	0	0	0	0	1	0	1	0	0	0	0
Ash	2	0	0	0	0	9	1	2	4	0	1	2	0
Balsam poplar	1	0	1	0	1	1	5	0	3	2	0	0	0
Paper birch	8	0	6	2	2	9	16	14	17	14	8	0	0
Bigtooth aspen	0	0	0	1	0	0	0	1	0	1	0	0	0
Quaking aspen	25	2	19	11	21	24	72	30	31	17	14	0	0
Basswood	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	0	0	0	0	0	0	0	0	0	0	0	4	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	36	2	26	15	25	43	95	46	56	34	23	6	0
Total all species	474	105	195	190	264	547	690	800	856	784	779	491	993
Number of plots	651	25	63	125	102	68	75	51	51	41	29	12	9
Standard error	19	31	28	17	28	59	68	71	84	84	94	75	195
Average basal area	71	30	41	54	64	78	88	88	89	95	98	72	107

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

Table 15.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Minnesota, 1977[1]

Balsam fir forest type - Site index class 0-50

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)										
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	13	0	17	7	9	7	13	18	51	0	36	0	0
Red pine	11	0	10	4	16	0	6	33	33	0	0	136	0
Jack pine	8	4	14	0	4	4	15	13	0	0	29	0	0
White spruce	20	3	15	0	12	23	17	41	51	0	103	0	0
Black spruce	58	65	38	38	34	76	64	72	88	29	84	0	0
Balsam fir	224	25	95	59	151	323	311	327	324	410	380	287	0
Tamarack	12	24	9	15	4	11	21	14	0	0	0	0	0
Northern white-cedar	53	32	17	72	69	35	66	26	146	56	55	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	400	153	215	194	299	479	513	543	693	496	688	423	0
Hardwoods:													
Select white oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Select red oaks	0	0	0	0	3	0	0	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	2	0	0	0	0	0	0	0
Hard maple	0	0	0	0	0	0	0	0	2	0	0	0	0
Soft maple	0	0	0	0	0	0	0	1	0	0	0	0	0
Ash	11	0	2	10	15	8	13	25	0	0	61	42	0
Balsam poplar	9	0	3	5	14	18	11	4	4	0	0	0	0
Paper birch	60	23	14	24	68	71	87	92	63	132	89	61	0
Bigtooth aspen	1	0	0	0	3	1	1	0	0	0	0	0	0
Quaking aspen	55	7	26	20	43	58	102	91	51	0	42	52	0
Basswood	0	0	0	0	0	0	0	2	0	0	0	0	0
Elm	1	0	0	0	1	0	4	0	5	0	0	40	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	139	30	45	59	147	160	219	214	126	132	191	194	0
Total all species	538	183	260	253	446	639	732	757	819	628	878	618	0
Number of plots	244	13	31	34	26	43	45	29	14	3	5	1	0
Standard error[3]	24	48	37	29	53	51	48	62	112	284	273	R	0
Average basal area	75	20	48	63	76	85	92	92	88	85	77	49	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 16.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Minnesota, 1977[1]

Balsam fir forest type - Site index class 51-60

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	21	0	20	0	0	10	32	70	0	0	0	636	0
Red pine	19	0	18	23	15	26	21	0	0	0	0	0	0
Jack pine	12	0	8	9	6	8	18	14	67	0	0	0	0
White spruce	50	75	10	0	52	38	56	117	0	356	0	284	0
Black spruce	47	0	10	63	55	50	50	36	82	0	0	103	0
Balsam fir	396	72	111	160	285	461	478	569	498	441	463	461	0
Tamarack	15	25	0	25	8	6	18	80	0	0	0	0	0
Northern white-cedar	56	9	22	30	52	38	60	44	394	0	753	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	614	180	201	310	473	637	732	931	1,041	797	1,215	1,484	0
Hardwoods:													
Select white oaks	0	0	0	0	0	1	0	0	0	0	0	0	0
Select red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	1	0	8	0	0	0	0	0	0	0	0	0	0
Soft maple	4	0	0	2	0	3	6	0	19	0	0	97	0
Ash	4	22	0	0	4	2	7	0	8	0	0	0	0
Balsam poplar	31	0	3	19	20	43	26	0	150	142	0	0	0
Paper birch	105	25	58	112	96	100	137	116	72	148	238	0	0
Bigtooth aspen	2	0	0	0	0	2	6	0	0	0	0	0	0
Quaking aspen	106	0	24	95	147	126	75	175	138	0	0	230	0
Basswood	1	0	0	8	0	3	0	0	0	0	0	0	0
Elm	3	0	7	0	0	4	3	0	0	0	0	0	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	256	47	101	235	267	282	260	291	388	290	238	327	0
Total all species	870	227	302	545	740	919	992	1,222	1,429	1,087	1,454	1,811	0
Number of plots	186	5	14	11	24	67	43	13	5	2	1	1	0
Standard error[3]	40	109	48	91	100	57	85	121	430	80	R	R	0
Average basal area	88	46	46	78	83	93	93	98	130	106	94	120	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 17.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Minnesota, 1977[1]

Balsam fir forest type - Site index class 61-70

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years) 0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	18	0	0	0	4	19	14	12	122	148	0	0	0
Red pine	49	20	0	0	20	10	194	12	267	0	0	0	0
Jack pine	4	16	0	0	4	7	0	0	0	0	0	0	0
White spruce	62	0	88	17	61	16	86	141	211	247	0	0	0
Black spruce	46	59	0	71	28	51	24	108	0	0	0	0	0
Balsam fir	557	266	183	333	405	652	769	905	169	143	0	0	0
Tamarack	10	0	0	0	8	14	27	0	0	0	0	0	0
Northern white-cedar	37	0	156	118	14	53	0	30	0	41	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	784	360	427	539	543	821	1,114	1,207	769	579	0	0	0
Hardwoods:													
Select white oaks	2	0	0	0	0	0	0	24	0	0	0	0	0
Select red oaks	1	0	0	0	0	2	0	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	2	0	0	0	0	6	0	0	0	0	0	0	0
Hard maple	4	0	0	0	0	7	0	19	0	0	0	0	0
Soft maple	1	0	0	0	0	0	0	9	0	0	0	0	0
Ash	10	0	0	38	6	14	5	0	33	0	0	0	0
Balsam poplar	41	0	0	14	47	25	25	186	0	0	0	0	0
Paper birch	129	12	0	79	148	140	198	143	36	101	0	0	0
Bigtooth aspen	0	0	0	0	0	0	0	0	0	0	0	0	0
Quaking aspen	165	255	0	39	93	194	190	261	37	211	0	0	0
Basswood	2	0	0	0	0	4	0	11	0	0	0	0	0
Elm	3	0	0	0	0	6	0	10	0	0	0	0	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	360	267	0	170	294	398	418	661	106	312	0	0	0
Total all species	1,144	627	427	709	837	1,219	1,533	1,868	874	891	0	0	0
Number of plots	67	5	2	5	12	21	11	7	2	2	0	0	0
Standard error	75	166	166	198	92	96	182	307	433	339	0	0	0
Average basal area	99	71	105	83	76	100	141	120	59	64	0	0	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

Table 18.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Minnesota, 1977[1]

Balsam fir forest type - Site index class 71-80

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	22	0	0	0	0	0	48	109	0	0	0	0	0
Red pine	7	0	0	0	0	0	21	0	0	0	0	0	0
Jack pine	21	0	0	0	0	0	68	0	0	0	0	0	0
White spruce	113	84	0	19	0	221	168	0	0	0	0	0	0
Black spruce	40	31	0	57	0	0	74	0	0	0	0	0	0
Balsam fir	405	86	0	158	303	1,096	321	556	0	0	0	0	0
Tamarack	2	0	0	12	0	0	0	0	0	0	0	0	0
Northern white-cedar	50	0	0	0	328	58	30	154	0	0	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	660	201	0	246	630	1,375	729	819	0	0	0	0	0
Hardwoods:													
Select white oaks	18	0	0	0	0	69	8	48	0	0	0	0	0
Select red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Soft maple	4	0	0	0	0	0	12	0	0	0	0	0	0
Ash	4	0	0	0	0	0	11	0	0	0	0	0	0
Balsam poplar	7	0	0	0	0	39	0	0	0	0	0	0	0
Paper birch	128	212	0	70	203	0	48	749	0	0	0	0	0
Bigtooth aspen	0	0	0	0	0	0	0	0	0	0	0	0	0
Quaking aspen	170	45	0	200	147	258	170	218	0	0	0	0	0
Basswood	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	3	0	0	0	0	16	0	0	0	0	0	0	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	334	257	0	270	350	382	249	1,015	0	0	0	0	0
Total all species	994	458	0	517	980	1,757	978	1,834	0	0	0	0	0
Number of plots	16	3	0	3	1	3	5	1	0	0	0	0	0
Standard error[3]	142	59	0	206	R	258	100	R	0	0	0	0	0
Average basal area	86	35	0	74	116	124	87	128	0	0	0	0	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 19.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Minnesota, 1977[1]

Balsam fir forest type - All site index classes

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years) 0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	17	0	17	4	4	10	22	32	46	42	30	318	0
Red pine	19	4	12	7	16	15	33	20	48	0	0	68	0
Jack pine	9	5	12	2	5	6	17	11	16	0	24	0	0
White spruce	40	25	17	3	36	35	52	72	54	172	86	142	0
Black spruce	52	48	28	54	40	57	54	65	78	13	70	51	0
Balsam fir	344	87	103	142	253	470	431	505	351	342	394	374	0
Tamarack	13	17	6	15	6	9	19	28	0	0	0	0	0
Northern white-cedar	52	18	24	62	56	40	56	36	191	36	171	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	546	204	220	289	417	641	684	769	783	606	776	953	0
Hardwoods:													
Select white oaks	1	0	0	0	0	2	0	4	0	0	0	0	0
Select red oaks	0	0	0	0	1	0	0	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	2	0	0	0	0	0	0	0
Hard maple	1	0	3	0	0	1	0	3	2	0	0	0	0
Soft maple	2	0	0	0	0	1	3	2	5	0	0	49	0
Ash	8	4	1	10	9	6	10	14	5	0	50	21	0
Balsam poplar	21	0	3	8	22	32	18	30	39	40	0	0	0
Paper birch	89	43	26	58	96	96	118	116	63	128	114	30	0
Bigtooth aspen	1	0	0	0	1	1	3	0	0	0	0	0	0
Quaking aspen	92	58	24	52	94	119	103	136	70	60	35	141	0
Basswood	2	0	0	2	0	3	0	10	0	0	0	0	0
Elm	2	0	2	0	1	4	3	1	3	0	0	20	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	219	105	60	130	224	268	258	316	186	229	199	261	0
Total all species	765	309	280	420	641	908	942	1,085	969	834	974	1,214	0
Number of plots	517	26	47	54	63	135	105	51	21	7	6	2	0
Standard error	24	55	29	62	51	43	50	88	136	153	243	597	0
Average basal area	83	37	50	70	79	93	98	99	95	85	80	85	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

Table 20.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Minnesota, 1977[1]

Northern white-cedar forest type - Site index class 0-50

(In cubic feet per acre)

		Stand-age class (years)											
Species	Average[2]	0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	7	0	0	0	0	6	7	0	2	12	0	6	19
Red pine	4	0	0	0	25	0	0	17	0	0	0	0	3
Jack pine	2	0	0	0	0	0	3	11	0	0	0	0	0
White spruce	5	0	0	4	0	5	5	4	4	1	0	15	9
Black spruce	79	0	0	23	114	126	102	88	72	102	92	68	61
Balsam fir	58	0	22	16	60	24	70	48	57	62	92	72	59
Tamarack	26	0	27	2	11	23	21	57	26	21	30	20	25
Northern white-cedar	481	179	110	146	206	232	389	340	385	609	492	585	800
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	661	179	159	190	416	416	597	564	547	807	706	764	977
Hardwoods:													
Select white oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Select red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	1	0	0	0	0	0	0	0	1	0	0	0	7
Hard maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Soft maple	0	0	0	0	0	0	0	0	0	1	0	0	0
Ash	21	0	5	0	0	32	4	14	21	16	10	5	66
Balsam poplar	10	0	9	1	0	5	17	11	7	13	25	10	6
Paper birch	42	0	12	8	26	47	19	33	49	37	52	61	60
Bigtooth aspen	1	0	0	0	0	0	0	0	6	0	0	0	0
Quaking aspen	10	0	0	1	0	0	21	26	11	2	11	8	7
Basswood	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	0	0	0	0	0	0	0	0	1	0	0	0	1
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	85	0	26	11	26	84	61	84	97	70	98	83	147
Total all species	746	179	185	200	443	501	658	648	644	877	804	848	1,124
Number of plots	318	2	8	17	14	10	27	40	37	41	27	40	55
Standard error	33	41	71	38	109	130	69	61	79	80	102	122	89
Average basal area	117	55	47	67	94	109	111	113	108	131	121	130	142

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

Table 21.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Minnesota, 1977[1]

Northern white-cedar forest type - All site index classes

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years) 0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	6	0	0	0	0	5	7	0	2	12	0	6	19
Red pine	4	0	0	0	22	0	0	17	0	0	0	0	3
Jack pine	2	0	0	0	0	4	3	10	0	0	0	0	0
White spruce	5	0	0	4	0	4	5	3	4	1	0	15	9
Black spruce	81	0	0	23	100	127	100	109	70	102	92	68	61
Balsam fir	62	0	22	16	67	69	75	57	55	62	92	72	59
Tamarack	26	0	27	2	10	26	25	50	26	21	30	20	25
Northern white-cedar	478	179	110	146	206	237	381	366	396	609	492	585	800
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	664	179	159	190	406	473	595	611	553	807	706	764	977
Hardwoods:													
Select white oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Select red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	2	0	0	0	0	0	0	0	4	0	0	0	7
Hard maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Soft maple	0	0	0	0	0	0	0	0	0	1	0	0	0
Ash	20	0	5	0	5	25	4	12	21	16	10	5	66
Balsam poplar	10	0	9	1	0	9	19	11	7	13	25	10	6
Paper birch	43	0	12	8	37	52	18	34	48	37	52	61	60
Bigtooth aspen	1	0	0	0	0	13	0	0	6	0	0	0	0
Quaking aspen	12	0	0	1	13	20	21	34	11	2	11	8	7
Basswood	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	0	0	0	0	0	0	0	0	1	0	0	0	1
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	89	0	26	11	54	119	61	92	98	70	98	83	147
Total all species	753	179	185	200	460	591	656	703	651	877	804	848	1,124
Number of plots	330	2	8	17	16	13	28	45	38	41	27	40	55
Standard error	32	41	71	38	98	135	66	62	77	80	102	122	89
Average basal area	116	55	47	67	90	106	109	115	108	131	121	130	142

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

Table 22.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Minnesota, 1977[1]

Tamarack forest type - Site index class 0-50

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	2	0	3	0	0	1	2	0	12	2	0	0	0
Red pine	1	0	0	0	0	0	0	0	14	2	0	0	0
Jack pine	3	0	0	2	0	13	0	18	0	0	0	5	0
White spruce	1	2	0	1	0	2	3	0	2	0	0	0	0
Black spruce	45	7	19	59	31	50	54	52	65	36	36	91	49
Balsam fir	7	4	5	0	2	0	18	26	29	6	0	1	0
Tamarack	293	80	101	109	82	322	268	399	332	457	762	616	564
Northern white-cedar	11	0	3	11	0	0	23	0	11	12	0	27	37
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	364	94	131	183	116	388	368	495	465	514	797	740	651
Hardwoods:													
Select white oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Select red oaks	0	2	0	0	0	0	0	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Soft maple	0	0	0	0	0	0	0	0	4	2	0	0	0
Ash	1	0	0	0	0	2	0	0	0	2	0	2	0
Balsam poplar	2	0	1	0	0	0	0	21	2	4	0	0	8
Paper birch	8	8	3	2	3	2	17	18	26	3	0	9	6
Bigtooth aspen	0	0	0	0	0	0	0	0	0	0	0	0	0
Quaking aspen	3	1	0	3	1	3	2	21	7	0	0	0	4
Basswood	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	2	0	0	1	0	6	0	2	7	4	0	3	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	16	11	3	6	4	13	19	62	45	15	0	14	18
Total all species	380	106	134	189	120	401	388	557	510	530	797	754	668
Number of plots	268	20	48	30	16	18	25	16	20	24	5	26	20
Standard error	21	26	20	29	31	58	53	87	80	56	188	66	68
Average basal area	53	27	32	53	47	63	51	52	67	61	75	71	70

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

Table 23.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Minnesota, 1977[1]

Tamarack forest type - Site index class 51-60

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years) 0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	8	0	22	0	0	29	0	0	15	0	0	0	0
Red pine	0	0	0	0	0	0	0	0	0	0	0	0	0
Jack pine	1	0	10	0	0	0	0	0	0	0	0	0	0
White spruce	1	0	0	0	0	0	3	0	0	0	0	0	0
Black spruce	60	0	90	0	52	64	73	125	37	0	0	0	0
Balsam fir	12	0	0	7	0	13	27	0	13	0	0	0	0
Tamarack	531	79	153	172	413	489	777	909	692	0	618	1,152	0
Northern white-cedar	9	0	10	0	69	0	0	0	22	0	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	622	79	285	180	534	596	881	1,034	779	0	618	1,152	0
Hardwoods:													
Select white oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Select red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Soft maple	1	0	0	4	0	6	0	0	0	0	0	0	0
Ash	4	0	0	0	0	0	0	0	70	0	0	0	0
Balsam poplar	1	0	0	0	0	0	3	0	0	0	0	0	0
Paper birch	4	0	0	0	0	8	9	0	0	0	0	0	0
Bigtooth aspen	0	0	0	0	0	0	0	0	0	0	0	0	0
Quaking aspen	10	0	40	26	0	0	3	0	0	0	0	0	0
Basswood	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	0	0	0	0	0	0	0	0	0	0	0	0	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	21	0	40	30	0	14	15	0	70	0	0	0	0
Total all species	643	79	326	209	534	610	896	1,034	849	0	618	1,152	0
Number of plots	48	1	7	6	4	7	15	3	3	0	1	1	0
Standard error[3]	71	R	113	85	208	151	150	172	169	0	R	R	0
Average basal area	50	11	34	25	47	45	67	61	61	0	41	60	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 24.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Minnesota, 1977[1]

Tamarack forest type - Site index class 61-70

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	6	0	0	0	0	0	0	0	0	62	0	0	0
Red pine	0	0	0	0	0	0	0	0	0	0	0	0	0
Jack pine	0	0	0	0	0	0	0	0	0	0	0	0	0
White spruce	4	0	0	0	0	0	14	0	0	0	0	0	0
Black spruce	30	0	0	0	66	0	0	0	0	106	0	0	0
Balsam fir	6	0	19	0	0	0	0	0	0	0	0	0	0
Tamarack	493	0	257	0	456	0	795	0	0	405	0	0	0
Northern white-cedar	0	0	0	0	0	0	0	0	0	0	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	539	0	275	0	522	0	809	0	0	572	0	0	0
Hardwoods:													
Select white oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Select red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Soft maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	0	0	0	0	0	0	0	0	0	0	0	0	0
Balsam poplar	40	0	63	0	0	0	69	0	0	0	0	0	0
Paper birch	6	0	20	0	0	0	0	0	0	0	0	0	0
Bigtooth aspen	0	0	0	0	0	0	0	0	0	0	0	0	0
Quaking aspen	56	0	62	0	0	0	123	0	0	0	0	0	0
Basswood	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	2	0	0	0	0	0	7	0	0	0	0	0	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	103	0	144	0	0	0	199	0	0	0	0	0	0
Total all species	642	0	420	0	522	0	1,009	0	0	572	0	0	0
Number of plots	10	0	3	0	3	0	3	0	0	1	0	0	0
Standard error[3]	104	0	125	0	202	0	74	0	0	R	0	0	0
Average basal area	66	0	83	0	43	0	79	0	0	49	0	0	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 25.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Minnesota, 1977[1]

Tamarack forest type - All site index classes

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years) 0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	3	0	6	0	0	9	1	0	12	4	0	0	0
Red pine	1	0	0	0	0	0	0	0	13	2	0	0	0
Jack pine	2	0	1	2	0	9	0	15	0	0	0	5	0
White spruce	1	2	0	1	0	2	4	0	2	0	0	0	0
Black spruce	47	7	26	49	39	50	58	64	61	38	30	87	49
Balsam fir	8	4	5	1	2	3	20	22	27	6	0	1	0
Tamarack	341	80	115	120	189	439	484	480	379	455	738	635	564
Northern white-cedar	10	0	4	10	12	0	13	0	12	11	0	26	37
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	413	93	157	182	241	511	579	580	506	517	768	755	651
Hardwoods:													
Select white oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Select red oaks	0	2	0	0	0	3	0	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Soft maple	1	0	0	1	0	2	0	0	3	2	0	0	0
Ash	1	0	0	0	0	1	0	0	9	2	0	2	0
Balsam poplar	5	0	4	0	0	0	20	17	2	4	0	0	8
Paper birch	7	7	3	1	2	4	13	15	23	3	0	9	6
Bigtooth aspen	0	0	0	0	0	0	0	0	0	0	0	0	0
Quaking aspen	6	1	8	7	1	2	11	18	6	0	0	0	4
Basswood	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	2	0	0	1	0	6	2	2	6	4	0	3	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	22	11	15	10	3	17	45	52	48	15	0	14	18
Total all species	435	104	172	192	244	528	624	632	554	531	768	769	668
Number of plots	329	21	58	36	23	27	44	19	23	25	6	27	20
Standard error	21	24	24	28	60	74	72	86	76	54	156	65	68
Average basal area	53	27	35	49	47	60	63	54	66	61	70	70	70

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

Table 26.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Minnesota, 1977[1/]

White spruce forest type - Site index class 61-70

(In cubic feet per acre)

Species	Average[2/]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	40	0	0	0	134	0	0	0	0	0	0	0	0
Red pine	0	0	0	0	0	0	0	0	0	0	0	0	0
Jack pine	33	0	0	0	0	0	334	0	0	0	0	0	0
White spruce	309	0	0	187	208	665	95	0	0	0	0	0	0
Black spruce	0	0	0	0	0	0	0	0	0	0	0	0	0
Balsam fir	85	0	0	0	120	165	0	0	0	0	0	0	0
Tamarack	21	0	0	0	0	70	0	0	0	0	0	0	0
Northern white-cedar	18	0	0	0	58	0	0	0	0	0	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	506	0	0	187	521	900	429	0	0	0	0	0	0
Hardwoods:													
Select white oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Select red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Soft maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	0	0	0	0	0	0	0	0	0	0	0	0	0
Balsam poplar	6	0	0	0	0	20	0	0	0	0	0	0	0
Paper birch	160	0	0	32	232	279	0	0	0	0	0	0	0
Bigtooth aspen	0	0	0	0	0	0	0	0	0	0	0	0	0
Quaking aspen	158	0	0	38	130	371	0	0	0	0	0	0	0
Basswood	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	0	0	0	0	0	0	0	0	0	0	0	0	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	324	0	0	69	362	670	0	0	0	0	0	0	0
Total all species	830	0	0	256	883	1,570	429	0	0	0	0	0	0
Number of plots	10	1	0	2	3	3	1	0	0	0	0	0	0
Standard error[3/]	249	R	0	256	464	405	R	0	0	0	0	0	0
Average basal area	71	0	0	49	91	100	38	0	0	0	0	0	0

[1/] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2/] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3/] R indicates that there was an insufficient number of plots to compute the standard error.

Table 27.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Minnesota, 1977[1]

White spruce forest type - All site index classes

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	25	0	0	0	100	0	15	32	0	188	0	0	0
Red pine	21	0	31	0	124	0	0	78	0	0	0	0	0
Jack pine	35	0	0	41	0	27	70	159	0	0	0	0	0
White spruce	302	0	21	161	188	453	364	525	56	575	948	593	0
Black spruce	21	0	0	0	0	53	28	76	0	0	0	0	0
Balsam fir	85	0	9	32	102	124	93	202	217	114	0	111	0
Tamarack	10	0	0	0	0	30	0	65	0	0	0	0	0
Northern white-cedar	34	0	0	0	44	0	24	0	799	90	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	535	0	62	235	558	686	593	1,137	1,071	966	948	705	0
Hardwoods:													
Select white oaks	1	0	0	0	0	0	0	0	0	12	0	0	0
Select red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Soft maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	0	0	0	0	0	0	0	0	0	0	0	0	0
Balsam poplar	12	0	0	0	0	9	11	81	0	29	0	0	0
Paper birch	83	19	11	21	204	119	55	22	180	79	390	181	0
Bigtooth aspen	0	0	0	0	0	0	0	0	0	0	0	0	0
Quaking aspen	105	0	0	88	114	232	138	0	0	313	0	0	0
Basswood	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	0	0	0	0	0	0	0	0	0	0	0	0	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	200	19	11	109	318	360	203	103	180	433	390	181	0
Total all species	735	19	73	344	876	1,046	797	1,240	1,251	1,399	1,338	886	0
Number of plots	40	5	4	3	4	7	9	3	1	2	1	1	0
Standard error[3]	95	19	43	172	328	260	131	308	R	256	R	R	0
Average basal area	65	4	17	62	86	84	80	83	98	104	70	64	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 28.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Minnesota, 1977[1]

Oak-hickory forest type - Site index class 0-50

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)										
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	2	1	2	0	0	0	0	0	6	2	2	2	0
Red pine	9	4	11	0	0	14	26	0	5	14	0	22	0
Jack pine	8	7	11	0	108	21	14	2	7	0	0	0	0
White spruce	1	0	0	0	0	2	2	3	0	0	0	2	0
Black spruce	0	0	0	0	0	0	0	0	1	0	0	0	0
Balsam fir	1	0	0	0	0	10	0	0	0	0	0	0	0
Tamarack	0	0	0	0	0	0	0	0	2	0	0	0	0
Northern white-cedar	0	0	0	0	0	0	0	0	0	0	0	0	0
Other softwoods	4	0	0	0	10	0	1	10	1	2	10	0	0
Total	24	11	24	0	118	47	43	16	22	17	11	26	0
Hardwoods:													
Select white oaks	254	50	75	63	62	185	113	253	272	431	321	306	255
Select red oaks	230	41	72	0	267	143	305	239	299	240	221	272	361
Other red oaks	9	0	0	0	0	2	0	2	4	12	31	8	0
Hickory	7	0	0	20	0	0	8	5	2	4	15	19	9
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	4	0	3	0	0	0	0	6	3	0	6	19	0
Soft maple	2	0	0	0	0	9	0	1	2	0	5	0	0
Ash	13	0	3	0	0	1	8	7	19	31	22	2	0
Balsam poplar	2	2	0	0	35	0	0	3	3	0	2	0	0
Paper birch	28	10	12	45	11	65	45	51	23	12	19	23	0
Bigtooth aspen	5	2	3	0	17	17	3	2	10	2	3	0	0
Quaking aspen	40	7	22	0	60	49	77	51	60	20	25	35	0
Basswood	22	0	0	0	0	51	11	19	20	17	35	39	29
Elm	33	9	14	26	9	18	15	35	31	54	42	40	37
Select hardwoods	8	0	0	0	5	0	6	4	6	16	16	14	6
Other hardwoods	3	0	0	0	0	0	0	7	3	7	4	3	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	659	120	205	154	467	540	591	686	757	846	766	779	698
Total all species	684	131	229	154	585	587	633	702	779	864	777	805	698
Number of plots	296	14	16	3	8	18	30	40	43	45	48	26	5
Standard error	23	29	36	23	101	72	44	59	54	72	42	96	113
Average basal area	79	30	47	35	76	77	79	82	92	87	85	84	86

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

Table 29.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Minnesota, 1977[1]

Oak-hickory forest type - Site index class 51-60

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years) 0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	3	0	0	0	0	0	3	0	20	0	0	0	0
Red pine	5	0	0	0	0	2	4	7	16	0	0	0	0
Jack pine	12	48	20	0	0	21	2	26	0	0	0	0	0
White spruce	0	0	0	0	0	1	0	0	0	0	0	0	0
Black spruce	0	0	0	0	0	0	0	0	0	0	0	0	0
Balsam fir	0	0	0	0	0	1	0	0	0	0	0	0	0
Tamarack	0	0	0	0	0	0	0	0	0	0	0	0	0
Northern white-cedar	0	0	0	0	0	0	0	0	0	0	0	0	0
Other softwoods	2	0	0	0	0	0	0	7	2	0	0	0	0
Total	23	48	20	0	0	25	9	41	38	0	0	0	0
Hardwoods:													
Select white oaks	168	0	81	0	188	125	206	195	127	252	182	249	0
Select red oaks	485	82	99	0	222	384	431	542	628	611	842	682	0
Other red oaks	9	20	0	0	0	3	4	16	27	0	5	0	0
Hickory	14	0	22	0	12	29	7	21	0	0	13	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	8	0	0	0	21	3	8	7	2	38	10	16	0
Soft maple	8	0	0	0	3	3	17	3	12	9	0	34	0
Ash	11	16	0	0	30	10	17	11	7	0	9	0	0
Balsam poplar	3	0	0	0	0	4	0	1	10	7	0	0	0
Paper birch	71	0	14	0	31	49	130	112	53	66	36	24	0
Bigtooth aspen	21	0	0	0	0	29	24	31	28	16	0	0	0
Quaking aspen	67	0	0	0	201	103	102	24	84	0	11	0	0
Basswood	35	15	0	0	22	12	47	29	60	47	64	70	0
Elm	37	0	0	0	26	24	18	44	53	58	92	56	0
Select hardwoods	12	0	0	0	30	10	6	15	4	30	16	4	0
Other hardwoods	6	0	0	0	0	2	1	9	11	41	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	956	133	217	0	787	791	1,017	1,061	1,106	1,176	1,281	1,137	0
Total all species	978	180	237	0	787	816	1,027	1,102	1,145	1,176	1,281	1,137	0
Number of plots	166	4	6	0	9	37	27	35	21	9	11	7	0
Standard error	39	104	41	0	162	56	102	82	110	130	136	153	0
Average basal area	89	27	53	0	91	84	96	93	100	89	104	91	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

Table 30.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Minnesota, 1977[1]

Oak-hickory forest type - Site index class 61-70

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)										
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:												
White pine	2	0	0	0	0	6	0	0	0	0	0	0	0
Red pine	4	0	87	0	0	7	0	0	0	0	0	0	0
Jack pine	0	0	0	0	0	0	0	0	0	0	0	0	0
White spruce	0	0	0	0	0	0	0	0	0	0	0	0	0
Black spruce	0	0	0	0	0	0	0	0	0	0	0	0	0
Balsam fir	1	0	0	15	0	0	0	3	0	0	0	0	0
Tamarack	1	0	0	0	0	3	0	0	0	0	0	0	0
Northern white-cedar	0	0	0	0	0	0	0	0	0	0	0	0	0
Other softwoods	1	0	0	0	0	0	0	5	0	0	0	0	0
Total	9	0	87	15	0	16	0	8	0	0	0	0	0
Hardwoods:												
Select white oaks	157	0	0	68	59	182	159	175	111	87	593	0	0
Select red oaks	550	217	312	118	423	530	718	542	714	678	613	0	0
Other red oaks	5	0	0	0	0	0	24	0	0	0	0	0	0
Hickory	29	0	0	0	66	1	25	87	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	11	0	0	0	8	13	9	18	9	0	0	0	0
Soft maple	12	0	0	6	7	33	4	6	0	0	0	0	0
Ash	11	0	0	0	4	20	9	2	26	0	12	0	0
Balsam poplar	1	0	0	0	0	5	0	0	0	0	0	0	0
Paper birch	87	0	63	42	56	129	95	100	0	0	23	0	0
Bigtooth aspen	17	0	0	0	7	15	36	8	31	0	0	0	0
Quaking aspen	85	0	0	0	114	110	107	73	16	173	0	0	0
Basswood	56	343	0	0	50	52	33	81	118	0	72	0	0
Elm	50	0	0	0	25	28	38	89	151	0	142	0	0
Select hardwoods	10	0	0	0	23	4	5	7	50	51	0	0	0
Other hardwoods	4	0	0	0	14	2	3	5	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	1,085	561	375	235	858	1,124	1,267	1,194	1,226	989	1,455	0	0
Total all species	1,093	561	461	250	858	1,141	1,267	1,202	1,226	989	1,455	0	0
Number of plots	102	1	2	6	10	29	23	19	7	2	3	0	0
Standard error[3]	50	R	250	51	132	93	101	87	152	278	423	0	0
Average basal area	92	52	58	41	76	98	99	102	91	94	100	0	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 31.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Minnesota, 1977[1]

Oak-hickory forest type - Site index class 71-80

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years) 0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	9	0	0	0	0	0	32	0	0	0	0	0	0
Red pine	6	0	0	0	12	0	0	0	0	0	0	96	0
Jack pine	6	0	120	0	0	0	0	0	0	0	0	0	0
White spruce	0	0	0	0	0	0	0	0	0	0	0	0	0
Black spruce	0	0	0	0	0	0	0	0	0	0	0	0	0
Balsam fir	0	0	0	0	0	0	0	0	0	0	0	0	0
Tamarack	0	0	0	0	0	0	0	0	0	0	0	0	0
Northern white-cedar	0	0	0	0	0	0	0	0	0	0	0	0	0
Other softwoods	4	0	0	0	15	0	0	0	0	0	0	0	0
Total	24	0	120	0	28	0	32	0	0	0	0	96	0
Hardwoods:													
Select white oaks	199	0	0	0	117	153	248	298	0	237	0	651	0
Select red oaks	672	0	0	0	324	865	887	852	0	599	0	1,002	0
Other red oaks	44	0	0	0	68	0	41	101	0	0	0	0	0
Hickory	41	0	0	0	74	8	45	50	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	5	0	0	0	10	0	11	0	0	0	0	0	0
Soft maple	12	0	0	0	0	11	30	0	0	0	0	62	0
Ash	5	0	0	0	9	6	4	0	0	0	0	0	0
Balsam poplar	2	0	0	0	0	0	8	0	0	0	0	0	0
Paper birch	57	0	0	0	69	69	85	0	0	0	0	104	0
Bigtooth aspen	15	0	0	0	13	49	7	0	0	0	0	0	0
Quaking aspen	62	0	58	0	66	79	79	21	0	0	0	96	0
Basswood	59	0	0	0	13	175	55	45	0	0	0	0	0
Elm	96	0	0	0	65	70	97	209	0	163	0	0	0
Select hardwoods	31	0	132	0	9	25	34	50	0	22	0	0	0
Other hardwoods	3	0	53	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	1,302	0	243	0	836	1,509	1,628	1,626	0	1,021	0	1,915	0
Total all species	1,326	0	363	0	864	1,509	1,660	1,626	0	1,021	0	2,011	0
Number of plots	41	0	2	0	11	8	11	6	0	2	0	1	0
Standard error[3]	92	0	7	0	90	230	148	136	0	341	0	R	0
Average basal area	96	0	53	0	79	111	110	98	0	75	0	139	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

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Table 32.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Minnesota, 1977[1]

Oak-hickory forest type - All site index classes

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)										
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:												
White pine	2	1	1	0	0	2	5	0	9	1	1	2	0
Red pine	7	3	13	0	3	5	10	3	8	11	0	20	0
Jack pine	7	15	21	0	21	12	5	10	4	0	0	0	0
White spruce	1	0	0	0	0	1	1	1	0	0	0	1	0
Black spruce	0	0	0	0	0	0	0	0	1	0	0	0	0
Balsam fir	1	0	0	10	0	2	0	1	0	0	0	0	0
Tamarack	0	0	0	0	0	1	0	0	1	0	0	0	0
Northern white-cedar	0	0	0	0	0	0	0	0	0	0	0	0	0
Other softwoods	3	0	0	0	6	0	0	8	1	1	7	0	0
Total	21	18	35	10	30	23	20	22	25	13	9	23	0
Hardwoods:												
Select white oaks	208	37	65	66	119	154	165	221	213	375	310	305	255
Select red oaks	398	59	91	79	352	478	537	439	437	323	350	378	361
Other red oaks	10	4	0	0	18	2	12	13	10	9	25	6	0
Hickory	15	0	5	7	39	14	16	29	1	3	14	15	9
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	6	0	2	0	9	5	6	8	3	6	6	18	0
Soft maple	6	0	0	4	4	13	9	3	4	1	4	9	0
Ash	11	3	2	0	12	10	10	7	16	23	19	1	0
Balsam poplar	2	2	0	0	7	3	1	2	5	1	1	0	0
Paper birch	52	8	16	43	47	80	88	79	30	20	22	25	0
Bigtooth aspen	13	1	2	0	8	29	18	13	17	4	3	0	0
Quaking aspen	58	5	18	0	106	100	92	44	63	27	21	29	0
Basswood	34	21	0	0	21	46	32	36	41	21	42	44	29
Elm	42	7	9	9	43	29	31	59	50	55	56	42	37
Select hardwoods	12	0	10	0	16	10	10	11	10	19	15	11	6
Other hardwoods	4	0	4	0	5	1	1	7	5	13	3	2	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	872	146	223	208	806	974	1,027	970	907	899	891	886	698
Total all species	892	164	259	218	836	997	1,048	992	931	912	899	909	698
Number of plots	618	19	26	9	41	98	93	100	71	60	62	34	5
Standard error	21	37	31	37	72	56	58	49	53	61	52	88	113
Average basal area	86	31	50	39	82	91	92	91	94	87	89	87	86

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

Table 33.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Minnesota, 1977[1]

Elm-ash-cottonwood forest type - Site index class 0-50

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years) 0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	3	0	0	0	8	0	0	0	4	3	26	0	0
Red pine	1	0	0	0	0	10	0	0	0	2	0	0	0
Jack pine	1	0	0	0	0	0	0	0	0	10	0	0	0
White spruce	5	4	12	0	0	2	9	2	3	17	0	0	18
Black spruce	5	0	0	3	9	13	4	0	6	9	0	9	0
Balsam fir	41	6	38	8	47	45	54	43	70	39	48	73	24
Tamarack	5	4	15	6	0	0	0	0	26	8	0	3	0
Northern white-cedar	36	12	30	9	13	8	45	9	14	64	51	149	0
Other softwoods	0	0	0	0	0	0	0	0	4	0	0	0	0
Total	98	26	94	25	78	78	112	54	127	151	125	235	43
Hardwoods:													
Select white oaks	5	2	0	2	0	2	17	3	0	8	22	0	0
Select red oaks	1	2	0	0	0	0	0	3	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	2	0	0	0	0	0	0	0	0	0
Hard maple	1	2	0	0	0	0	3	0	0	0	0	4	0
Soft maple	11	23	0	0	4	6	2	4	3	9	3	0	274
Ash	255	79	127	119	114	266	321	368	279	373	323	395	251
Balsam poplar	19	11	7	12	17	17	18	17	70	16	16	15	33
Paper birch	34	7	23	7	27	79	26	54	71	26	18	53	30
Bigtooth aspen	1	0	0	4	0	0	2	0	0	0	0	0	0
Quaking aspen	27	15	0	14	15	36	46	62	60	10	38	7	8
Basswood	16	0	0	0	10	0	27	27	3	55	7	19	42
Elm	55	9	41	14	53	30	69	83	96	80	33	61	230
Select hardwoods	0	0	0	0	0	0	0	0	0	0	2	0	0
Other hardwoods	21	0	0	1	2	41	4	120	0	3	60	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	445	149	198	176	242	477	535	740	581	579	522	554	867
Total all species	543	175	292	201	320	555	647	794	708	730	646	789	910
Number of plots	218	22	18	21	14	18	24	20	15	25	19	17	5
Standard error	27	27	48	37	69	51	59	100	73	88	79	119	277
Average basal area	73	30	51	43	56	84	86	92	94	84	90	97	90

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

Table 34.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Minnesota, 1977[1]

Elm-ash-cottonwood forest type - Site index class 51-60

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	2	0	0	0	0	0	4	2	7	0	0	0	0
Red pine	0	0	0	0	0	0	0	0	0	0	0	0	0
Jack pine	1	0	0	0	0	0	0	5	0	0	0	0	0
White spruce	12	0	6	0	9	16	12	18	12	4	5	0	55
Black spruce	4	0	0	0	0	9	0	4	6	5	0	0	20
Balsam fir	54	0	55	31	15	38	66	82	50	37	59	141	56
Tamarack	4	71	0	0	0	0	0	0	7	0	0	0	0
Northern white-cedar	26	0	0	37	0	10	10	6	6	71	95	77	124
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	103	71	61	68	24	72	93	116	90	116	160	218	254
Hardwoods:													
Select white oaks	12	0	0	0	5	0	6	12	35	26	28	0	0
Select red oaks	2	0	0	0	7	0	3	0	6	0	0	0	0
Other red oaks	1	0	0	0	0	0	0	0	8	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	7	0	0	0	0	0	3	3	6	16	40	0	19
Hard maple	4	0	0	0	0	2	13	7	4	0	0	0	0
Soft maple	18	0	4	0	25	4	20	2	18	0	78	135	0
Ash	445	129	103	42	268	427	421	581	441	925	444	306	720
Balsam poplar	33	27	11	0	26	64	16	19	40	23	85	14	57
Paper birch	43	8	14	25	6	38	34	40	83	4	93	135	43
Bigtooth aspen	0	0	0	0	0	0	0	0	0	0	0	0	0
Quaking aspen	35	37	5	11	27	60	29	37	26	39	41	32	84
Basswood	9	0	8	28	7	2	7	6	20	17	0	48	0
Elm	113	11	42	112	15	79	103	72	186	159	174	195	257
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	23	0	0	159	0	25	34	29	11	0	26	44	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	747	212	187	376	384	699	689	808	884	1,208	1,008	910	1,180
Total all species	850	283	248	444	409	771	782	924	974	1,324	1,168	1,128	1,434
Number of plots	175	8	12	5	7	22	33	25	24	14	15	4	6
Standard error	42	82	45	108	111	74	73	86	101	177	205	227	275
Average basal area	82	31	36	60	65	78	83	88	89	105	104	93	119

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

Table 35.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Minnesota, 1977[1]

Elm-ash-cottonwood forest type - Site index class 61-70

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)										
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:												
White pine	1	0	0	0	0	0	0	5	0	0	0	0	0
Red pine	0	0	0	0	0	0	0	0	0	0	0	0	0
Jack pine	0	0	0	0	0	0	0	0	0	0	0	0	0
White spruce	6	0	28	0	0	37	5	0	0	0	0	0	0
Black spruce	0	0	0	0	0	0	0	0	0	0	0	0	0
Balsam fir	31	0	0	0	26	0	51	38	26	67	0	18	67
Tamarack	3	0	0	0	0	0	10	6	0	0	0	0	0
Northern white-cedar	24	0	0	0	93	0	16	16	0	0	0	172	69
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	65	0	28	0	119	37	81	65	26	67	0	190	135
Hardwoods:													
Select white oaks	14	22	0	0	0	21	5	12	45	43	0	0	18
Select red oaks	3	0	0	0	0	20	0	3	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	1	0	0	0	0	0	0	5	0	0	0	0	0
Hard maple	2	0	0	0	0	0	0	9	0	0	0	0	0
Soft maple	88	0	25	0	0	43	94	103	324	97	63	0	0
Ash	452	39	274	69	230	253	474	665	301	521	687	698	673
Balsam poplar	52	0	0	286	36	10	101	36	98	20	0	0	0
Paper birch	43	44	27	0	0	20	81	61	19	41	0	54	14
Bigtooth aspen	11	0	0	0	0	0	0	5	0	0	0	225	0
Quaking aspen	39	20	23	0	64	82	44	55	0	56	0	0	0
Basswood	17	0	0	0	0	49	21	18	0	32	0	0	43
Elm	149	42	0	0	76	122	98	107	406	91	165	294	493
Select hardwoods	4	18	0	20	0	6	8	3	0	0	0	0	0
Other hardwoods	117	37	0	309	388	316	74	55	32	0	304	0	90
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	993	222	348	683	795	943	998	1,139	1,225	901	1,219	1,271	1,331
Total all species	1,058	222	376	683	914	979	1,079	1,204	1,250	968	1,219	1,462	1,467
Number of plots	71	3	3	2	5	7	15	16	7	4	3	3	3
Standard error	61	86	112	329	205	134	114	142	167	170	183	416	291
Average basal area	88	31	39	71	108	83	87	94	101	67	102	114	116

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

Table 36.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Minnesota, 1977[1]

Elm-ash-cottonwood forest type - Site index class 71-80

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	0	0	0	0	0	0	0	0	0	0	0	0	0
Red pine	0	0	0	0	0	0	0	0	0	0	0	0	0
Jack pine	0	0	0	0	0	0	0	0	0	0	0	0	0
White spruce	0	0	0	0	0	0	0	0	0	0	0	0	0
Black spruce	0	0	0	0	0	0	0	0	0	0	0	0	0
Balsam fir	31	0	0	44	0	28	43	0	56	0	0	0	0
Tamarack	4	0	0	0	0	0	11	0	0	0	0	0	0
Northern white-cedar	4	0	0	0	0	15	0	0	0	0	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	38	0	0	44	0	42	53	0	56	0	0	0	0
Hardwoods:													
Select white oaks	22	0	0	0	0	0	26	0	0	370	0	0	0
Select red oaks	7	0	0	0	0	0	22	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	5	0	0	0	0	0	0	0	41	0	0	0	0
Soft maple	193	0	0	0	0	434	89	411	187	0	0	0	0
Ash	350	0	21	114	333	520	311	51	552	654	0	0	0
Balsam poplar	77	0	0	15	316	21	102	0	226	0	0	0	0
Paper birch	43	0	0	0	0	118	38	0	0	0	0	0	0
Bigtooth aspen	3	0	0	0	0	0	8	0	0	0	0	0	0
Quaking aspen	26	0	57	21	0	0	62	0	0	0	0	0	0
Basswood	45	0	0	0	0	17	66	0	0	514	0	0	0
Elm	143	0	62	45	41	110	158	244	241	204	0	0	0
Select hardwoods	2	0	0	0	0	0	7	0	0	0	0	0	0
Other hardwoods	199	0	20	218	0	258	254	349	32	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	1,117	0	160	414	689	1,478	1,144	1,055	1,279	1,741	0	0	0
Total all species	1,155	0	160	457	689	1,520	1,197	1,055	1,335	1,741	0	0	0
Number of plots	27	0	2	2	1	7	9	2	3	1	0	0	0
Standard error[3]	147	0	4	70	R	361	170	556	637	R	0	0	0
Average basal area	95	0	36	83	98	108	104	72	92	109	0	0	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 37.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Minnesota, 1977[1]

Elm-ash-cottonwood forest type - All site index classes

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)										
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	2	0	0	0	4	0	2	2	5	1	13	0	0
Red pine	0	0	0	0	0	3	0	0	0	1	0	0	0
Jack pine	1	0	0	0	0	0	0	2	0	6	0	0	0
White spruce	7	3	10	0	2	12	8	8	7	11	2	0	30
Black spruce	3	0	0	2	5	8	1	2	5	6	0	7	8
Balsam fir	43	4	38	13	33	34	55	55	53	40	48	78	47
Tamarack	4	20	8	4	0	0	3	2	12	4	0	2	0
Northern white-cedar	29	8	15	12	24	8	20	9	7	59	65	140	68
Other softwoods	0	0	0	0	0	0	0	0	1	0	0	0	0
Total	90	35	72	32	69	65	88	78	90	129	129	227	153
Hardwoods:													
Select white oaks	10	3	0	1	1	3	11	9	23	25	23	0	4
Select red oaks	2	1	0	0	2	3	4	2	3	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	4	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	3	0	0	1	0	0	1	2	3	5	16	0	8
Hard maple	3	1	0	0	0	1	8	5	5	0	0	3	0
Soft maple	41	15	3	0	9	81	47	60	67	14	38	23	98
Ash	353	87	125	103	184	356	372	511	378	569	402	418	543
Balsam poplar	32	14	7	29	34	35	40	22	69	18	43	13	36
Paper birch	38	11	19	9	15	59	39	48	65	20	47	67	32
Bigtooth aspen	2	0	0	3	0	0	2	1	0	0	0	28	0
Quaking aspen	31	21	7	13	27	46	38	48	31	23	36	10	39
Basswood	15	0	3	5	7	9	21	15	11	51	3	22	24
Elm	96	12	39	32	47	71	95	107	193	109	101	113	298
Select hardwoods	1	2	0	1	0	1	2	1	0	0	1	0	0
Other hardwoods	54	3	1	63	73	133	88	73	12	2	66	7	19
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	681	171	205	259	398	797	768	903	864	835	775	703	1,101
Total all species	771	206	276	291	467	862	856	982	954	964	904	930	1,254
Number of plots	497	33	35	30	27	55	85	64	49	44	37	24	14
Standard error	25	28	31	44	72	80	47	66	72	88	101	111	170
Average basal area	80	30	44	51	69	86	87	91	92	90	97	98	108

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

Table 38.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Minnesota, 1977[1]

Maple-basswood forest type - Site index class 0-50

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	6	0	20	0	0	7	0	10	14	3	4	14	0
Red pine	0	0	0	0	0	0	0	0	3	0	0	0	0
Jack pine	1	0	0	0	0	8	0	0	0	0	0	0	0
White spruce	4	4	0	0	0	6	10	6	0	4	0	2	14
Black spruce	1	0	0	0	0	3	2	0	0	0	0	0	0
Balsam fir	32	0	0	0	39	22	30	33	23	56	57	60	26
Tamarack	1	0	22	0	0	3	0	0	0	0	0	0	0
Northern white-cedar	11	0	0	0	0	3	14	0	8	3	51	22	25
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	57	4	43	0	39	52	56	48	49	66	111	99	65
Hardwoods:													
Select white oaks	34	19	3	5	16	14	63	62	45	39	21	16	45
Select red oaks	33	0	6	2	4	2	59	56	82	30	33	24	15
Other red oaks	0	0	0	0	0	0	0	0	3	0	0	0	0
Hickory	2	10	0	0	0	0	4	0	3	0	0	6	0
Yellow birch	3	0	0	0	0	0	0	0	2	0	13	20	0
Hard maple	78	15	34	19	47	10	68	94	86	64	144	220	109
Soft maple	20	9	31	10	0	19	17	32	9	13	47	30	8
Ash	64	3	26	63	20	52	85	92	67	91	63	76	23
Balsam poplar	12	0	0	0	8	13	8	39	11	11	12	0	13
Paper birch	41	12	31	24	72	59	36	41	69	31	26	43	28
Bigtooth aspen	4	0	0	0	0	0	12	8	9	0	7	0	0
Quaking aspen	49	13	20	48	9	47	27	98	19	15	131	3	158
Basswood	127	3	0	5	20	166	125	148	128	189	67	153	398
Elm	125	54	33	121	76	77	69	184	126	179	187	166	137
Select hardwoods	2	5	0	0	0	2	3	4	0	0	9	2	0
Other hardwoods	8	14	0	4	0	16	0	24	7	5	11	3	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	602	159	184	300	273	477	576	881	666	669	770	762	933
Total all species	659	163	227	300	312	529	632	930	714	735	881	862	998
Number of plots	200	10	9	11	9	24	25	24	22	24	18	15	9
Standard error	33	39	36	55	58	72	67	121	77	57	182	92	159
Average basal area	80	28	54	57	61	75	82	95	91	87	90	88	99

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[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

Table 39.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Minnesota, 1977[1]

Maple-basswood forest type - Site index class 51-60

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years) 0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	8	4	0	0	4	4	14	11	9	0	0	0	49
Red pine	1	0	0	0	0	0	2	3	0	0	0	0	0
Jack pine	2	0	0	0	0	0	0	12	0	0	0	8	0
White spruce	10	10	0	0	20	9	8	4	23	13	0	0	16
Black spruce	1	0	0	0	0	0	0	3	1	0	0	0	0
Balsam fir	29	4	25	9	31	45	36	32	23	5	32	10	12
Tamarack	4	0	0	27	10	5	1	1	9	0	0	0	0
Northern white-cedar	7	7	0	0	6	3	1	5	12	13	46	0	20
Other softwoods	1	0	0	0	0	0	0	0	0	5	12	0	0
Total	62	25	25	36	71	65	63	72	77	35	90	18	97
Hardwoods:													
Select white oaks	53	32	0	0	29	23	47	91	92	27	71	62	70
Select red oaks	53	59	26	26	34	41	78	50	49	74	38	88	0
Other red oaks	1	0	0	0	0	2	1	1	0	3	0	0	0
Hickory	2	0	0	0	4	5	0	2	0	0	0	6	0
Yellow birch	8	0	0	0	0	18	4	1	27	0	14	0	0
Hard maple	118	22	26	0	51	79	172	90	145	165	220	97	349
Soft maple	30	0	35	32	27	30	24	40	30	17	29	58	0
Ash	75	51	48	19	51	71	52	115	91	70	103	82	54
Balsam poplar	18	13	17	0	9	17	8	6	4	101	38	40	8
Paper birch	68	30	29	41	57	129	93	65	38	26	48	54	0
Bigtooth aspen	7	0	0	0	0	6	13	14	9	0	3	0	0
Quaking aspen	50	4	27	77	82	59	58	48	52	25	47	30	0
Basswood	190	37	19	20	106	156	198	232	199	257	228	356	352
Elm	137	93	23	23	99	72	90	154	221	172	110	415	166
Select hardwoods	3	0	0	0	0	2	7	10	1	0	0	0	0
Other hardwoods	6	0	0	0	2	1	16	2	9	8	5	9	21
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	820	340	250	237	550	712	860	925	967	946	954	1,295	1,021
Total all species	882	365	275	273	622	777	922	996	1,044	981	1,044	1,313	1,118
Number of plots	317	10	12	8	23	49	61	51	46	19	17	16	5
Standard error	26	55	53	59	56	48	58	65	55	121	90	158	97
Average basal area	91	52	53	47	75	90	96	93	104	94	99	107	114

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

Table 40.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Minnesota, 1977[1]

Maple-basswood forest type - Site index class 61-70

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years) 0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	11	0	5	0	0	7	0	23	13	0	69	0	0
Red pine	0	0	0	0	0	1	0	0	0	0	0	0	0
Jack pine	1	0	12	0	0	0	2	0	0	0	0	0	0
White spruce	5	0	5	0	9	0	2	6	7	0	0	25	23
Black spruce	1	0	17	0	0	4	0	0	0	0	0	0	0
Balsam fir	25	0	3	0	10	39	26	23	47	3	13	0	60
Tamarack	1	0	0	17	0	1	0	0	0	7	0	0	0
Northern white-cedar	3	0	0	0	0	0	0	0	3	0	0	16	101
Other softwoods	2	0	0	0	0	0	2	8	0	0	0	0	0
Total	48	0	42	17	19	51	31	60	70	10	82	41	184
Hardwoods:													
Select white oaks	61	0	11	20	19	50	50	80	81	39	19	92	20
Select red oaks	66	0	32	10	57	76	75	84	80	180	56	48	0
Other red oaks	1	0	17	0	0	0	0	0	0	5	0	0	0
Hickory	1	0	6	0	0	0	0	0	0	15	0	0	0
Yellow birch	3	0	0	0	0	12	1	0	9	3	0	0	0
Hard maple	146	0	20	60	256	102	153	105	168	56	397	214	328
Soft maple	30	0	23	0	31	30	40	24	16	74	30	15	46
Ash	85	0	4	56	76	52	106	96	94	61	108	90	279
Balsam poplar	14	0	0	0	0	24	27	6	16	0	0	12	28
Paper birch	71	0	26	51	116	52	92	82	69	19	94	71	10
Bigtooth aspen	9	0	3	0	0	11	10	1	27	12	0	10	0
Quaking aspen	49	249	101	37	87	44	62	61	23	5	5	8	0
Basswood	247	0	50	18	74	288	328	182	380	289	313	175	0
Elm	229	0	18	48	83	140	142	304	334	503	281	395	645
Select hardwoods	6	0	0	5	3	2	2	20	6	5	10	0	0
Other hardwoods	23	0	2	12	3	16	12	34	40	51	47	4	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	1,043	249	314	318	805	899	1,099	1,079	1,343	1,317	1,361	1,134	1,356
Total all species	1,091	249	356	335	825	950	1,130	1,139	1,412	1,327	1,443	1,175	1,540
Number of plots	233	2	12	7	13	34	53	42	31	13	12	10	4
Standard error	35	249	37	61	91	62	62	65	108	160	153	165	261
Average basal area	97	34	54	52	83	100	101	96	110	102	110	100	133

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

Table 41.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Minnesota, 1977[1]

Maple-basswood forest type - Site index class 71-80

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)										
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	14	0	0	0	0	8	7	51	0	0	0	0	0
Red pine	1	0	0	0	0	0	7	0	0	0	0	0	0
Jack pine	0	0	0	0	0	0	0	0	0	0	0	0	0
White spruce	10	0	0	0	0	28	9	0	15	37	0	0	0
Black spruce	0	0	0	0	0	0	0	0	0	0	0	0	0
Balsam fir	32	0	0	0	0	43	73	9	51	56	0	0	0
Tamarack	0	0	0	0	0	0	0	0	0	0	0	0	0
Northern white-cedar	9	0	0	0	0	29	0	0	0	80	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	66	0	0	0	0	108	96	60	66	173	0	0	0
Hardwoods:													
Select white oaks	58	0	30	58	54	24	89	49	60	12	246	0	0
Select red oaks	62	0	0	90	74	45	46	49	92	112	183	0	0
Other red oaks	4	0	0	0	0	21	0	0	0	0	0	0	0
Hickory	4	0	0	0	9	4	4	0	10	0	0	0	0
Yellow birch	2	0	0	0	0	0	5	5	0	0	0	0	0
Hard maple	176	0	37	79	143	72	190	151	320	223	242	787	624
Soft maple	16	0	0	0	19	0	43	27	0	0	0	0	0
Ash	86	0	20	62	74	107	56	105	118	0	54	0	590
Balsam poplar	5	0	0	0	0	6	0	11	18	0	0	0	0
Paper birch	101	0	0	181	134	106	133	55	55	245	99	0	0
Bigtooth aspen	6	0	0	20	0	0	22	5	0	0	0	0	0
Quaking aspen	84	0	0	172	118	158	68	93	0	56	0	0	0
Basswood	347	0	0	136	303	260	346	429	451	500	599	122	212
Elm	270	0	148	233	115	222	160	367	450	542	244	0	601
Select hardwoods	6	0	0	16	5	10	5	10	0	0	0	0	0
Other hardwoods	26	0	35	37	0	19	43	24	36	51	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	1,253	0	269	1,084	1,048	1,055	1,209	1,378	1,610	1,742	1,666	909	2,028
Total all species	1,319	0	269	1,084	1,048	1,162	1,306	1,438	1,676	1,915	1,666	909	2,028
Number of plots	80	0	3	3	10	14	15	17	9	4	3	1	1
Standard error[3]	69	0	87	236	159	139	105	140	202	470	587	R	R
Average basal area	100	0	50	71	88	101	106	101	111	121	128	98	112

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 42.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Minnesota, 1977[1]

Maple-basswood forest type - Site index class 81-91

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years) 0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	4	0	0	0	17	0	0	0	0	0	0	0	0
Red pine	0	0	0	0	0	0	0	0	0	0	0	0	0
Jack pine	0	0	0	0	0	0	0	0	0	0	0	0	0
White spruce	0	0	0	0	0	0	0	0	0	0	0	0	0
Black spruce	0	0	0	0	0	0	0	0	0	0	0	0	0
Balsam fir	30	0	0	0	73	22	0	0	0	104	0	0	0
Tamarack	0	0	0	0	0	0	0	0	0	0	0	0	0
Northern white-cedar	11	0	0	0	46	0	0	0	0	0	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	45	0	0	0	136	22	0	0	0	104	0	0	0
Hardwoods:													
Select white oaks	40	0	0	0	16	16	108	20	0	0	0	0	0
Select red oaks	96	0	0	0	0	261	157	0	0	0	0	0	0
Other red oaks	19	0	0	0	0	95	0	0	0	0	0	0	0
Hickory	18	0	0	0	0	46	0	76	0	0	0	0	0
Yellow birch	8	0	0	0	21	17	0	0	0	0	0	0	0
Hard maple	102	0	0	0	49	239	79	0	253	0	0	0	0
Soft maple	69	0	0	0	121	23	101	62	0	0	0	0	0
Ash	120	0	0	0	155	14	98	291	154	64	0	0	0
Balsam poplar	2	0	0	0	9	0	0	0	0	0	0	0	0
Paper birch	85	0	0	0	92	228	61	0	0	0	0	0	0
Bigtooth aspen	42	0	0	0	73	75	35	0	0	0	0	0	0
Quaking aspen	110	0	0	0	244	210	36	0	0	0	0	0	0
Basswood	415	0	0	0	312	548	532	92	490	388	0	0	0
Elm	422	0	0	0	193	22	726	504	187	1,160	0	0	0
Select hardwoods	9	0	0	0	0	0	31	0	0	0	0	0	0
Other hardwoods	29	0	0	0	0	0	89	0	0	51	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	1,587	0	0	0	1,286	1,794	2,053	1,045	1,085	1,662	0	0	0
Total all species	1,633	0	0	0	1,422	1,816	2,053	1,045	1,085	1,766	0	0	0
Number of plots	25	0	0	0	6	5	7	3	2	2	0	0	0
Standard error	150	0	0	0	143	390	238	498	484	1,042	0	0	0
Average basal area	113	0	0	0	122	132	125	72	86	83	0	0	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

Table 43.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Minnesota, 1977[1]

Maple-basswood forest type - All site index classes

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	9	2	7	0	3	6	6	19	10	1	18	5	13
Red pine	1	0	0	0	0	0	2	1	1	0	0	0	0
Jack pine	1	0	4	0	0	2	1	4	0	0	0	3	0
White spruce	7	6	2	0	9	8	6	4	13	8	0	7	16
Black spruce	1	0	6	0	0	2	0	1	0	0	0	0	0
Balsam fir	29	2	9	2	26	38	34	26	32	30	34	25	28
Tamarack	2	0	6	12	4	3	0	0	4	2	0	0	0
Northern white-cedar	7	3	0	0	7	5	2	2	7	10	34	12	38
Other softwoods	1	0	0	0	0	0	1	3	0	1	4	0	0
Total	57	13	33	14	49	62	51	61	67	52	90	52	95
Hardwoods:													
Select white oaks	51	23	7	13	28	28	57	76	75	61	60	41	40
Select red oaks	54	27	21	20	37	52	76	60	67	49	40	64	11
Other red oaks	2	0	6	0	0	7	0	1	1	2	0	0	0
Hickory	2	5	2	0	3	4	1	3	1	3	0	4	0
Yellow birch	5	0	0	0	2	11	2	1	14	1	9	7	0
Hard maple	123	17	27	30	116	78	148	101	156	107	236	185	245
Soft maple	28	4	27	12	31	25	34	33	19	26	34	36	14
Ash	78	25	26	49	70	64	77	108	91	70	87	80	115
Balsam poplar	14	6	6	0	5	16	13	12	10	35	17	18	14
Paper birch	67	19	26	51	91	96	87	63	53	45	54	53	15
Bigtooth aspen	8	0	1	2	7	8	14	8	13	2	4	2	0
Quaking aspen	54	31	47	66	92	69	54	65	32	18	64	15	75
Basswood	214	18	23	26	139	221	260	223	262	274	212	235	292
Elm	180	67	34	88	104	106	138	240	252	295	187	311	276
Select hardwoods	4	2	0	3	2	3	5	12	2	1	6	1	0
Other hardwoods	14	7	4	8	1	10	18	18	19	20	17	6	6
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	896	249	256	368	728	799	984	1,023	1,067	1,008	1,028	1,057	1,103
Total all species	952	263	289	382	777	861	1,036	1,084	1,134	1,061	1,118	1,109	1,198
Number of plots	858	22	36	29	62	126	162	137	110	63	50	42	19
Standard error	19	40	25	57	57	42	41	44	52	79	92	83	113
Average basal area	92	40	53	54	82	93	98	95	103	95	100	99	111

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

Table 44.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Minnesota, 1977[1]

Aspen forest type - Site index class 0-50

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years) 0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	2	1	0	0	0	6	3	4	0	0	0	69	0
Red pine	9	0	0	0	28	2	0	75	7	13	0	29	0
Jack pine	7	10	3	2	0	2	9	34	0	0	0	0	0
White spruce	6	1	0	2	3	6	8	34	0	0	0	23	0
Black spruce	7	1	5	0	7	9	11	11	6	0	0	91	0
Balsam fir	30	1	8	33	31	27	42	74	32	208	46	0	72
Tamarack	3	1	1	0	0	0	12	0	0	16	0	0	0
Northern white-cedar	7	1	1	6	0	0	9	48	8	11	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	71	16	18	43	68	52	95	279	54	248	46	212	72
Hardwoods:													
Select white oaks	14	4	4	0	10	11	20	37	46	61	0	79	73
Select red oaks	11	0	0	0	13	23	16	35	16	7	0	13	54
Other red oaks	0	0	0	0	0	2	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	3	0	4	2	0	1	0	0	22	0	56	0	138
Soft maple	3	0	1	0	5	7	6	3	0	0	0	12	0
Ash	13	2	4	2	8	19	22	0	71	13	495	0	0
Balsam poplar	20	13	7	10	25	28	33	26	28	11	0	73	0
Paper birch	39	2	28	17	24	44	83	63	73	24	0	24	221
Bigtooth aspen	6	0	2	2	2	12	20	7	0	0	43	0	0
Quaking aspen	194	68	91	52	151	358	323	299	291	165	0	128	717
Basswood	8	0	2	0	5	9	12	2	42	0	0	0	493
Elm	8	1	3	0	2	17	23	8	5	7	0	0	76
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	1	0	0	0	0	2	0	0	0	17	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	321	91	145	85	245	531	557	480	594	306	595	327	1,772
Total all species	391	108	163	128	313	583	652	758	648	554	642	539	1,844
Number of plots	245	40	51	19	21	35	41	19	9	6	1	2	1
Standard error[3]	24	23	21	28	71	50	51	104	106	157	R	64	R
Average basal area	56	26	40	38	57	76	73	86	83	72	75	75	142

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 45.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Minnesota, 1977[1]

Aspen forest type - Site index class 51-60

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years) 0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	7	8	1	2	4	9	8	10	6	48	0	0	0
Red pine	9	7	1	1	4	3	15	5	55	134	0	0	0
Jack pine	19	6	18	11	20	17	28	43	22	8	0	0	0
White spruce	11	5	5	3	14	4	25	18	37	0	0	0	0
Black spruce	9	1	2	8	16	9	5	38	18	7	0	0	0
Balsam fir	30	7	13	7	32	39	54	56	50	36	0	0	0
Tamarack	1	0	2	0	1	0	2	0	0	0	0	0	0
Northern white-cedar	3	1	6	1	3	1	3	4	2	0	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	89	35	49	32	96	81	140	174	190	233	0	0	0
Hardwoods:													
Select white oaks	16	6	6	8	18	24	25	30	14	30	0	0	0
Select red oaks	15	8	2	2	11	29	19	19	27	90	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	2	1	0	1	1	2	3	4	0	19	0	0	0
Soft maple	6	1	1	1	1	11	7	23	9	22	0	0	0
Ash	11	3	6	12	10	12	10	26	34	30	0	0	0
Balsam poplar	27	34	14	9	48	25	34	24	34	8	0	0	0
Paper birch	51	20	14	23	26	65	88	105	106	101	0	0	0
Bigtooth aspen	19	2	5	1	1	24	26	34	176	14	0	0	0
Quaking aspen	307	97	132	125	341	421	493	550	448	363	0	0	0
Basswood	6	0	4	4	2	17	9	3	5	30	0	0	0
Elm	13	4	2	5	5	20	22	19	35	61	0	0	0
Select hardwoods	0	0	0	0	0	0	0	1	0	0	0	0	0
Other hardwoods	1	0	1	0	6	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	476	176	187	190	471	651	737	839	889	767	0	0	0
Total all species	565	211	236	222	567	732	877	1,013	1,079	1,000	0	0	0
Number of plots	668	124	102	58	68	109	112	65	22	8	0	0	0
Standard error	19	26	16	19	39	29	47	70	102	248	0	0	0
Average basal area	62	28	46	47	70	75	81	94	94	92	0	0	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

Table 46.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Minnesota, 1977[1]

Aspen forest type - Site index class 61-70

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years) 0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	9	11	6	1	2	3	18	8	13	85	0	0	0
Red pine	14	6	4	4	5	18	16	26	72	33	0	0	0
Jack pine	15	6	7	19	13	10	28	18	8	75	0	0	0
White spruce	13	5	6	5	9	5	20	30	46	29	164	0	0
Black spruce	7	3	1	4	3	3	10	17	44	27	0	0	0
Balsam fir	45	15	21	22	27	55	70	70	71	99	47	0	0
Tamarack	2	0	0	1	1	4	4	1	0	0	0	0	0
Northern white-cedar	5	1	2	2	1	5	5	23	0	48	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	109	47	46	57	60	102	170	193	254	396	212	0	0
Hardwoods:													
Select white oaks	20	10	12	11	23	29	23	13	19	20	0	0	0
Select red oaks	27	10	8	5	30	28	34	52	51	72	64	0	0
Other red oaks	0	0	0	0	2	0	1	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	2	0	0	0	0
Hard maple	6	2	3	1	7	6	6	13	11	17	55	0	0
Soft maple	7	4	2	2	5	11	10	7	15	4	0	0	0
Ash	16	8	8	13	19	15	15	39	23	13	0	0	0
Balsam poplar	35	12	20	23	30	39	59	35	48	50	17	0	0
Paper birch	88	29	33	43	71	118	127	112	149	78	193	0	0
Bigtooth aspen	27	2	0	0	10	45	52	41	27	0	0	0	0
Quaking aspen	472	101	156	245	437	590	679	699	710	987	909	0	0
Basswood	15	10	9	0	13	12	19	24	40	21	121	0	0
Elm	12	4	6	9	11	10	17	24	27	5	0	0	0
Select hardwoods	1	0	0	0	1	1	1	0	0	4	0	0	0
Other hardwoods	1	0	0	1	3	1	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	727	192	257	354	661	907	1,043	1,057	1,122	1,271	1,359	0	0
Total all species	836	239	303	411	722	1,009	1,214	1,250	1,376	1,667	1,571	0	0
Number of plots	1,135	154	107	82	154	270	225	93	35	11	4	0	0
Standard error	18	17	19	26	30	31	42	63	99	269	462	0	0
Average basal area	75	34	52	55	72	88	94	97	100	114	110	0	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

Table 47.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Minnesota, 1977[1]

Aspen forest type - Site index class 71-80

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years) 0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	8	2	3	2	9	8	12	7	54	69	40	0	0
Red pine	16	12	2	10	7	22	25	29	0	119	0	0	0
Jack pine	19	7	9	27	22	22	13	8	57	79	0	0	0
White spruce	10	10	2	6	10	13	11	14	0	0	23	0	0
Black spruce	6	5	5	4	6	4	8	20	39	0	28	0	0
Balsam fir	63	17	21	32	51	85	79	118	161	99	258	0	0
Tamarack	4	4	3	4	6	3	3	0	0	0	0	0	0
Northern white-cedar	5	1	1	0	4	8	2	0	0	156	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	130	57	46	84	114	164	152	197	311	522	349	0	0
Hardwoods:													
Select white oaks	17	12	5	14	20	21	19	12	17	0	0	0	0
Select red oaks	30	9	10	19	30	35	43	35	141	8	0	0	0
Other red oaks	1	0	1	0	0	0	3	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	5	1	0	2	5	6	6	7	24	24	0	0	0
Soft maple	8	3	2	8	7	12	10	6	13	5	0	0	0
Ash	20	11	2	9	25	21	25	30	0	42	46	0	0
Balsam poplar	50	31	39	31	36	62	67	71	172	64	54	0	0
Paper birch	94	29	30	68	91	116	121	154	238	123	59	0	0
Bigtooth aspen	32	1	6	5	30	43	49	46	0	286	0	0	0
Quaking aspen	597	129	191	405	608	698	826	1,226	755	777	769	0	0
Basswood	15	7	10	8	13	20	22	6	10	5	0	0	0
Elm	14	8	7	9	9	18	22	28	0	0	55	0	0
Select hardwoods	1	0	0	2	0	1	0	0	0	0	0	0	0
Other hardwoods	1	0	5	1	1	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	883	241	308	580	875	1,053	1,212	1,620	1,369	1,333	983	0	0
Total all species	1,013	297	354	664	989	1,217	1,365	1,816	1,681	1,855	1,331	0	0
Number of plots	954	94	78	82	215	267	164	34	8	8	4	0	0
Standard error	22	20	26	54	28	32	42	309	211	252	208	0	0
Average basal area	82	33	53	69	82	93	101	113	116	126	98	0	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

Table 48.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Minnesota, 1977[1]

Aspen forest type - Site index class 81-90

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years) 0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	9	3	6	12	10	8	6	26	0	0	111	0	0
Red pine	14	0	0	20	19	6	13	66	0	0	0	0	0
Jack pine	16	0	5	15	27	16	6	8	42	0	0	0	0
White spruce	8	4	0	6	8	7	16	25	0	0	0	0	0
Black spruce	8	27	0	4	6	3	10	20	77	0	0	0	0
Balsam fir	75	29	39	65	70	97	75	109	156	0	0	0	0
Tamarack	2	0	0	5	2	2	4	0	0	0	0	0	0
Northern white-cedar	2	0	0	0	6	1	0	0	0	0	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	135	63	50	126	148	141	131	254	275	0	111	0	0
Hardwoods:													
Select white oaks	15	7	14	23	15	11	24	15	13	0	0	0	0
Select red oaks	25	3	3	20	31	28	35	0	0	0	0	248	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	3	0	0	0	0	0	0	0	0	0	0
Hard maple	7	0	0	7	9	2	15	5	0	0	175	0	0
Soft maple	12	6	41	9	7	13	17	0	0	0	0	0	0
Ash	26	0	13	14	32	17	52	47	43	0	0	0	0
Balsam poplar	61	50	22	35	68	52	82	164	128	0	0	0	0
Paper birch	98	60	112	69	112	110	89	24	40	0	0	971	0
Bigtooth aspen	46	4	0	6	25	86	86	4	117	0	0	0	0
Quaking aspen	814	150	244	608	802	1,030	1,023	1,045	914	0	1,551	268	0
Basswood	21	4	50	30	12	19	30	41	0	0	229	0	0
Elm	16	3	10	9	18	19	26	5	0	0	0	0	0
Select hardwoods	0	0	0	0	0	0	1	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	1,142	287	513	830	1,132	1,386	1,481	1,350	1,254	0	1,955	1,487	0
Total all species	1,277	350	563	956	1,280	1,526	1,612	1,604	1,529	0	2,066	1,487	0
Number of plots	420	25	21	56	121	119	58	14	4	0	1	1	0
Standard error[3]	34	56	45	63	47	59	101	255	472	0	R	R	0
Average basal area	93	37	73	83	94	101	108	104	107	0	165	109	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 49.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Minnesota, 1977[1]

Aspen forest type - Site index class 91-100

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years) 0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	12	0	0	18	2	5	12	152	37	0	0	0	0
Red pine	10	0	0	0	23	11	0	0	0	0	0	0	0
Jack pine	14	0	57	0	25	7	27	0	0	0	0	0	0
White spruce	47	60	0	0	46	63	81	152	0	0	0	0	0
Black spruce	13	0	0	36	0	26	0	0	0	0	0	0	0
Balsam fir	103	0	0	122	66	175	112	42	85	0	0	0	0
Tamarack	0	0	0	0	0	0	0	0	0	0	0	0	0
Northern white-cedar	11	0	0	0	0	10	31	175	0	0	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	209	60	57	176	162	296	264	521	121	0	0	0	0
Hardwoods:													
Select white oaks	23	0	16	61	15	12	10	146	0	0	0	0	0
Select red oaks	35	0	0	24	14	71	70	17	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	11	0	0	4	9	10	21	0	66	0	0	0	0
Soft maple	12	27	0	9	13	16	0	0	22	0	0	0	0
Ash	64	0	0	18	93	28	98	136	231	0	192	0	0
Balsam poplar	118	14	0	63	149	162	98	0	162	0	113	0	0
Paper birch	123	73	142	169	139	114	52	44	220	0	0	0	0
Bigtooth aspen	31	0	0	0	20	42	32	394	0	0	0	0	0
Quaking aspen	990	492	366	938	904	1,239	1,039	879	1,279	0	752	0	0
Basswood	23	0	0	24	38	20	20	0	0	0	34	0	0
Elm	36	0	0	6	47	26	127	0	0	0	62	0	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	1,468	606	524	1,315	1,449	1,740	1,569	1,616	1,980	0	1,154	0	0
Total all species	1,677	666	581	1,490	1,603	2,036	1,833	2,137	2,101	0	1,154	0	0
Number of plots	74	4	2	12	22	20	8	2	3	0	1	0	0
Standard error[3]	84	116	353	215	127	130	251	61	747	0	R	0	0
Average basal area	108	74	57	109	103	119	117	115	129	0	109	0	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 50.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Minnesota, 1977[1]

Aspen forest type - All site index classes

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	8	7	3	4	6	6	12	10	14	57	25	46	0
Red pine	13	7	2	7	10	14	17	27	47	75	0	19	0
Jack pine	16	6	10	17	20	15	20	24	17	46	0	0	0
White spruce	11	6	4	5	11	9	18	25	30	10	68	15	0
Black spruce	7	4	2	6	6	5	9	23	32	11	10	60	0
Balsam fir	51	12	18	34	47	70	68	76	75	103	115	0	72
Tamarack	2	1	1	2	3	2	4	0	0	3	0	0	0
Northern white-cedar	4	1	3	1	3	5	4	16	1	56	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	114	44	43	76	105	128	152	202	216	360	218	141	72
Hardwoods:													
Select white oaks	18	8	8	15	19	22	22	21	20	25	0	52	73
Select red oaks	24	8	5	11	27	31	33	35	45	49	23	91	54
Other red oaks	0	0	0	0	0	0	1	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	1	0	0	0	0
Hard maple	5	1	1	3	6	5	6	8	12	16	41	0	138
Soft maple	8	3	4	5	6	12	10	11	11	8	0	8	0
Ash	18	6	6	11	25	17	22	32	38	24	79	0	0
Balsam poplar	42	24	20	25	46	49	57	44	62	36	36	48	0
Paper birch	81	26	32	54	82	106	111	106	135	85	91	340	221
Bigtooth aspen	28	2	3	3	19	46	47	38	65	73	4	0	0
Quaking aspen	507	109	154	346	568	672	698	725	628	635	820	174	717
Basswood	14	5	9	9	12	17	18	14	24	16	68	0	493
Elm	13	5	5	7	12	16	22	20	22	18	26	0	76
Select hardwoods	0	0	0	0	0	1	1	0	0	1	0	0	0
Other hardwoods	1	0	1	0	2	1	0	0	0	3	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	759	198	249	490	825	994	1,048	1,054	1,063	988	1,188	714	1,772
Total all species	872	242	292	566	930	1,122	1,201	1,256	1,279	1,349	1,406	855	1,844
Number of plots	3,496	441	361	309	601	820	608	227	81	33	11	3	1
Standard error[3]	11	12	11	28	21	20	26	62	73	150	198	318	R
Average basal area	76	32	50	63	81	90	93	98	99	104	107	86	142

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 51.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Minnesota, 1977[1]

Paper birch forest type - Site index class 0-50

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years) 0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	12	0	0	0	4	3	20	50	23	0	0	0	0
Red pine	8	0	0	0	14	0	4	6	48	10	0	0	0
Jack pine	8	0	0	0	0	0	18	19	33	0	0	0	0
White spruce	18	0	13	0	14	37	24	6	49	7	0	0	0
Black spruce	13	0	0	16	22	26	8	22	0	33	0	0	0
Balsam fir	61	10	48	55	70	69	36	92	134	43	97	0	0
Tamarack	5	0	4	0	5	0	19	0	0	0	0	0	0
Northern white-cedar	13	31	4	0	31	4	3	11	0	61	0	0	0
Other softwoods	1	0	0	0	0	0	6	0	0	0	0	0	0
Total	140	41	70	70	161	138	136	206	287	155	97	0	0
Hardwoods:													
Select white oaks	9	0	0	7	3	10	0	17	28	37	0	0	0
Select red oaks	10	17	6	0	3	10	12	0	18	22	0	108	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	1	0	0	0	0	0	5	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	2	0	2	0	0	0	8	0	0	0	0	0	0
Soft maple	3	0	6	0	0	0	7	0	0	12	0	0	0
Ash	21	0	3	0	5	54	29	39	11	38	0	0	0
Balsam poplar	9	0	3	16	0	10	9	23	11	20	0	0	0
Paper birch	212	47	59	81	238	299	314	313	238	181	20	86	0
Bigtooth aspen	4	0	0	0	0	20	2	0	0	0	50	0	0
Quaking aspen	73	22	31	85	71	139	96	82	71	29	23	0	0
Basswood	6	0	0	0	0	28	7	2	13	0	0	0	0
Elm	10	0	13	12	6	6	6	1	6	22	129	0	0
Select hardwoods	1	0	0	0	4	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	361	86	123	201	331	577	495	476	395	360	222	194	0
Total all species	501	127	193	272	492	715	632	682	681	515	319	194	0
Number of plots	103	6	16	5	13	13	20	11	9	7	2	1	0
Standard error[3]	35	34	29	57	117	87	66	107	108	129	125	R	0
Average basal area	67	24	48	62	68	85	77	72	80	67	83	23	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 52.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Minnesota, 1977[1]

Paper birch forest type - Site index class 51-60

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)										
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	13	12	22	15	14	5	20	14	16	0	0	0	0
Red pine	18	0	10	0	0	14	23	5	100	9	46	0	0
Jack pine	11	0	0	9	5	20	8	11	17	0	0	0	0
White spruce	23	15	0	0	20	12	33	16	76	26	35	0	0
Black spruce	4	28	0	0	0	6	4	5	0	0	0	0	0
Balsam fir	97	20	10	21	78	82	120	98	82	216	343	65	0
Tamarack	3	0	10	0	4	3	4	0	0	0	0	0	0
Northern white-cedar	14	0	0	0	4	8	5	5	41	79	43	164	0
Other softwoods	1	0	0	0	0	0	2	0	0	0	0	0	0
Total	182	74	52	45	126	149	218	154	332	329	466	229	0
Hardwoods:													
Select white oaks	8	0	0	10	2	5	5	16	0	47	42	13	0
Select red oaks	23	0	0	7	14	27	24	52	15	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	2	0	0	0	0	0	0	17	0	0	0	0	0
Yellow birch	0	0	0	0	3	0	0	0	0	0	0	0	0
Hard maple	11	35	0	0	4	15	9	11	19	0	0	36	0
Soft maple	15	20	23	13	4	29	11	9	6	9	19	0	0
Ash	31	10	0	0	23	20	29	40	51	86	61	128	0
Balsam poplar	19	6	15	7	32	19	18	2	15	47	138	79	0
Paper birch	474	193	126	229	313	520	464	553	645	728	427	547	0
Bigtooth aspen	7	0	6	37	0	5	4	12	9	0	0	36	0
Quaking aspen	125	0	18	106	131	107	159	101	166	239	94	32	0
Basswood	17	0	0	0	3	15	16	26	0	38	75	107	0
Elm	13	0	0	15	3	16	5	21	25	18	30	54	0
Select hardwoods	0	0	0	0	4	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	746	263	189	424	535	777	743	859	951	1,213	885	1,032	0
Total all species	928	337	241	468	660	927	961	1,013	1,283	1,541	1,352	1,261	0
Number of plots	200	5	9	7	15	52	57	28	12	10	2	3	0
Standard error	36	72	52	112	65	61	62	75	191	194	95	113	0
Average basal area	87	71	47	58	71	89	90	93	102	115	102	96	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

Table 53.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Minnesota, 1977[1]

Paper birch forest type - Site index class 61-70

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years) 0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	17	0	0	14	6	9	24	27	54	0	0	0	0
Red pine	33	0	18	0	27	15	52	44	86	14	0	0	0
Jack pine	10	0	14	0	34	5	5	14	7	0	0	0	0
White spruce	12	13	15	0	3	11	12	15	39	14	0	0	0
Black spruce	5	0	0	0	0	1	5	21	0	0	0	0	0
Balsam fir	79	14	52	0	46	85	79	95	98	180	447	0	0
Tamarack	4	0	0	0	24	1	1	0	0	0	0	0	0
Northern white-cedar	16	0	11	0	11	5	14	4	38	255	85	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	176	27	110	14	150	133	192	220	321	464	532	0	0
Hardwoods:													
Select white oaks	9	0	15	6	8	6	12	12	4	15	0	0	0
Select red oaks	47	0	0	73	31	41	59	70	47	59	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	3	0	0	0	0	3	4	0	17	14	0	0	0
Hard maple	12	0	0	0	9	14	4	18	35	38	0	0	0
Soft maple	18	7	0	0	4	18	34	12	28	0	0	0	0
Ash	26	0	0	38	19	34	11	20	48	68	0	253	0
Balsam poplar	28	13	0	32	19	41	28	19	11	30	177	0	0
Paper birch	591	179	248	325	545	616	664	632	580	666	287	835	0
Bigtooth aspen	15	0	0	0	14	19	16	7	12	77	0	0	0
Quaking aspen	135	14	91	86	98	125	173	161	137	127	200	318	0
Basswood	22	0	0	0	14	25	25	31	22	11	69	0	0
Elm	22	0	0	0	21	30	16	24	19	18	59	0	0
Select hardwoods	0	0	0	0	0	0	1	2	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	928	212	355	560	784	973	1,047	1,007	959	1,122	791	1,406	0
Total all species	1,105	239	465	574	933	1,106	1,239	1,227	1,281	1,586	1,323	1,406	0
Number of plots	226	5	6	6	32	71	53	32	13	6	1	1	0
Standard error[3]	35	85	136	141	91	53	62	103	145	202	R	R	0
Average basal area	92	60	65	85	83	91	98	94	98	107	105	116	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 54.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Minnesota, 1977[1]

Paper birch forest type - Site index class 71-80

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)										
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:												
White pine	10	0	0	0	0	11	7	70	0	0	0	0	0
Red pine	61	0	0	0	8	39	12	133	680	0	0	0	0
Jack pine	19	0	0	0	0	2	94	0	0	0	0	0	0
White spruce	23	0	55	0	0	25	27	0	58	0	44	0	0
Black spruce	2	0	39	0	0	0	0	0	0	0	0	0	0
Balsam fir	110	0	95	0	94	63	185	117	227	0	262	0	0
Tamarack	1	0	0	82	0	0	0	0	0	0	0	0	0
Northern white-cedar	13	0	0	0	0	0	0	63	94	0	143	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	239	0	189	82	102	139	325	382	1,059	0	449	0	0
Hardwoods:												
Select white oaks	15	0	0	0	8	13	26	37	25	0	0	0	0
Select red oaks	40	0	0	0	80	61	0	0	0	0	0	0	0
Other red oaks	1	0	0	0	0	2	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	2	0	0	0	0	0	0	0	44	0	0	0	0
Hard maple	12	0	0	0	5	14	16	0	49	0	0	0	0
Soft maple	20	0	0	0	5	20	50	9	0	0	0	0	0
Ash	31	0	0	0	24	25	39	20	0	0	232	0	0
Balsam poplar	81	0	0	281	117	61	53	150	14	0	307	0	0
Paper birch	646	0	217	0	425	740	646	610	970	0	1,168	0	0
Bigtooth aspen	12	0	0	0	30	14	6	0	0	0	0	0	0
Quaking aspen	168	0	75	70	226	165	189	182	92	0	46	0	0
Basswood	17	0	0	0	15	18	9	0	100	0	0	0	0
Elm	25	0	0	0	8	38	20	32	0	0	41	0	0
Select hardwoods	1	0	0	0	0	2	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	1,072	0	291	351	943	1,172	1,054	1,040	1,294	0	1,795	0	0
Total all species	1,310	0	480	433	1,045	1,311	1,379	1,423	2,353	0	2,244	0	0
Number of plots	63	0	3	1	11	27	12	4	3	0	2	0	0
Standard error[3]	81	0	167	R	128	92	171	260	847	0	210	0	0
Average basal area	97	0	50	41	87	103	99	93	133	0	126	0	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 55.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Minnesota, 1977[1]

Paper birch forest type - All site index classes

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	15	3	10	10	6	8	21	35	30	0	0	0	0
Red pine	28	0	6	0	15	23	30	28	129	11	13	0	0
Jack pine	11	0	2	3	15	9	16	13	16	0	0	0	0
White spruce	18	8	13	0	7	15	23	13	55	17	23	0	0
Black spruce	5	8	3	4	4	4	5	14	0	10	0	0	0
Balsam fir	86	13	43	22	72	80	98	95	112	154	264	39	0
Tamarack	3	0	5	4	11	2	5	0	0	0	0	0	0
Northern white-cedar	14	11	4	0	11	5	7	8	34	119	65	98	0
Other softwoods	0	0	0	0	0	0	2	0	0	0	0	0	0
Total	180	44	86	44	141	145	206	206	376	311	365	137	0
Hardwoods:													
Select white oaks	10	0	3	7	10	7	9	15	10	36	12	8	0
Select red oaks	31	6	3	25	28	37	33	49	26	22	0	22	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	1	0	0	0	0	0	1	6	0	0	0	0	0
Yellow birch	1	0	0	0	0	1	1	0	9	4	0	0	0
Hard maple	10	10	1	0	7	13	7	11	22	10	0	22	0
Soft maple	15	10	9	5	3	21	23	9	12	8	5	0	0
Ash	27	3	1	12	22	30	23	30	36	67	84	127	0
Balsam poplar	28	5	5	32	38	35	23	20	12	34	152	47	0
Paper birch	493	136	130	209	439	582	533	555	550	545	502	512	0
Bigtooth aspen	10	0	2	14	14	14	8	7	7	20	14	22	0
Quaking aspen	126	12	46	92	122	132	158	126	127	146	75	83	0
Basswood	17	0	0	0	15	21	17	23	19	19	31	64	0
Elm	17	0	6	9	15	25	11	20	16	19	66	32	0
Select hardwoods	0	0	0	0	2	0	0	1	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	788	182	206	404	715	918	848	872	846	929	942	939	0
Total all species	968	226	292	448	856	1,063	1,054	1,079	1,223	1,241	1,307	1,076	0
Number of plots	603	17	35	19	77	165	142	76	37	23	7	5	0
Standard error[3]	23	39	39	65	57	38	42	59	122	145	303	231	0
Average basal area	87	49	51	67	80	92	92	90	98	98	104	86	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 56.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Minnesota, 1977[1]

Balsam poplar forest type - Site index class 0-50

(In cubic feet per acre)

		Stand-age class (years)											
Species	Average[2]	0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	1	0	0	0	0	0	0	0	12	0	0	0	0
Red pine	0	0	0	0	0	0	0	0	0	0	0	0	0
Jack pine	7	0	0	0	0	46	0	0	0	0	0	0	0
White spruce	6	0	0	0	6	16	26	0	0	0	0	0	0
Black spruce	2	0	0	0	4	0	0	0	18	0	0	0	0
Balsam fir	25	0	5	0	0	24	86	11	195	0	0	0	0
Tamarack	2	0	0	0	0	0	0	0	0	138	0	0	0
Northern white-cedar	1	0	0	0	0	0	0	0	16	0	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	44	0	5	0	10	86	112	11	240	138	0	0	0
Hardwoods:													
Select white oaks	1	0	3	0	2	0	0	0	4	0	0	0	0
Select red oaks	1	0	0	0	0	0	0	0	14	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Soft maple	0	0	0	0	0	0	5	0	0	0	0	0	0
Ash	17	0	5	0	3	33	0	33	128	0	0	0	0
Balsam poplar	209	176	66	71	168	345	392	336	427	198	0	0	0
Paper birch	24	0	0	6	16	9	38	12	208	109	0	0	0
Bigtooth aspen	1	0	0	0	0	0	0	0	17	0	0	0	0
Quaking aspen	70	41	46	65	76	99	110	156	19	0	0	0	0
Basswood	6	0	0	0	0	38	0	0	0	0	0	0	0
Elm	7	0	0	0	11	7	0	4	36	90	0	0	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	1	0	4	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	338	217	123	143	277	531	545	542	853	397	0	0	0
Total all species	382	217	128	143	287	618	657	553	1,093	535	0	0	0
Number of plots	76	9	15	9	15	12	6	4	5	1	0	0	0
Standard error[3]	39	76	36	36	49	87	82	87	117	R	0	0	0
Average basal area	51	25	35	34	48	70	65	62	108	56	0	0	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 57.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Minnesota, 1977[1]

Balsam poplar forest type - Site index class 51-60

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years) 0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	1	0	0	0	0	0	6	0	0	0	0	0	0
Red pine	0	0	0	0	0	0	0	0	0	0	0	0	0
Jack pine	1	0	0	0	0	0	0	15	0	0	0	0	0
White spruce	7	4	19	0	0	3	11	9	12	0	0	0	0
Black spruce	6	6	0	0	0	11	18	0	0	0	0	0	0
Balsam fir	47	7	9	0	17	89	39	172	34	56	0	0	0
Tamarack	4	0	8	0	0	0	0	0	40	0	0	0	0
Northern white-cedar	8	0	8	0	3	20	9	0	7	0	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	73	18	44	0	20	122	83	196	92	56	0	0	0
Hardwoods:													
Select white oaks	2	8	0	0	0	3	0	0	0	0	0	0	0
Select red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	2	0	0	0	0	0	0	0	0	159	0	0	0
Hard maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Soft maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	36	4	0	0	4	68	38	68	77	369	0	0	0
Balsam poplar	329	133	64	375	284	517	525	290	410	493	0	0	0
Paper birch	32	3	0	17	29	55	50	37	12	315	0	0	0
Bigtooth aspen	1	0	0	0	0	4	0	0	0	0	0	0	0
Quaking aspen	67	38	24	60	106	65	82	106	89	62	0	0	0
Basswood	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	16	15	11	0	23	20	15	8	26	0	0	0	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	1	0	0	0	3	0	3	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	485	200	99	452	448	732	713	510	614	1,397	0	0	0
Total all species	559	218	142	452	468	854	796	706	707	1,453	0	0	0
Number of plots	92	14	14	3	13	21	13	7	6	1	0	0	0
Standard error[3]	49	48	28	177	57	119	139	207	109	R	0	0	0
Average basal area	61	32	33	77	64	83	72	64	56	124	0	0	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 58.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Minnesota, 1977[1]

Balsam poplar forest type - Site index class 61-70

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	1	0	0	0	0	3	0	0	0	0	0	0	0
Red pine	1	0	0	6	0	0	0	0	0	0	0	0	0
Jack pine	1	5	0	0	0	0	0	0	0	0	0	0	0
White spruce	11	21	0	0	0	4	25	11	35	45	0	0	0
Black spruce	5	10	0	0	3	14	6	0	0	0	0	0	0
Balsam fir	74	33	4	12	79	105	84	133	183	107	0	0	0
Tamarack	22	0	11	0	0	28	43	60	0	0	0	0	0
Northern white-cedar	24	0	2	0	46	10	38	47	99	0	0	0	0
Other softwoods	1	0	0	0	0	4	0	0	0	0	0	0	0
Total	138	69	17	18	129	168	197	250	317	152	0	0	0
Hardwoods:													
Select white oaks	3	0	8	0	3	0	5	0	15	0	0	0	0
Select red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	4	0	0	4	0	11	0	9	0	0	0	0	0
Soft maple	0	0	0	0	3	0	0	0	0	0	0	0	0
Ash	44	14	7	16	47	26	24	87	264	258	166	0	0
Balsam poplar	410	58	156	180	464	503	515	703	588	654	869	0	0
Paper birch	49	12	18	5	59	94	19	104	82	73	0	0	0
Bigtooth aspen	0	0	0	0	0	0	0	0	0	0	0	0	0
Quaking aspen	93	67	52	67	152	95	105	140	16	140	0	0	0
Basswood	5	5	0	0	0	0	12	0	14	97	0	0	0
Elm	27	6	8	8	32	14	32	48	73	208	64	0	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	634	161	248	280	760	743	711	1,091	1,051	1,431	1,098	0	0
Total all species	772	230	266	298	889	911	908	1,342	1,368	1,582	1,098	0	0
Number of plots	119	11	17	11	13	24	23	12	5	2	1	0	0
Standard error[3]	49	63	62	37	92	107	80	100	308	48	R	0	0
Average basal area	68	22	40	49	81	78	69	106	102	111	120	0	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 59 --Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Minnesota, 1977[1]

Balsam poplar forest type - Site index class 71-80

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	2	0	0	0	0	0	11	0	0	0	0	0	0
Red pine	3	0	0	0	0	0	20	0	0	0	0	0	0
Jack pine	2	0	0	0	0	0	16	0	0	0	0	0	0
White spruce	14	19	13	0	14	25	0	0	0	79	0	0	0
Black spruce	1	7	0	0	2	0	0	0	0	0	0	0	0
Balsam fir	100	18	14	66	89	126	239	50	0	163	0	0	0
Tamarack	1	0	0	0	2	0	0	0	0	0	0	0	0
Northern white-cedar	14	0	0	20	0	0	0	0	0	858	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	137	44	26	86	107	150	286	50	0	1,100	0	0	0
Hardwoods:													
Select white oaks	10	0	4	59	4	0	20	0	0	0	0	0	0
Select red oaks	4	0	0	0	5	9	5	0	0	0	0	0	0
Other red oaks	1	0	0	0	0	5	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	7	0	0	0	21	0	12	19	0	0	0	0	0
Soft maple	2	0	0	0	7	0	0	0	0	0	0	0	0
Ash	32	36	6	60	0	45	41	74	0	194	0	0	0
Balsam poplar	566	135	112	436	464	917	797	1,256	0	849	0	0	0
Paper birch	57	10	18	43	94	50	86	0	0	216	0	0	0
Bigtooth aspen	0	0	0	0	0	0	0	0	0	0	0	0	0
Quaking aspen	139	10	60	106	131	213	227	165	0	0	0	0	0
Basswood	8	10	0	10	12	0	13	30	0	0	0	0	0
Elm	49	0	53	10	22	76	64	274	0	0	0	0	0
Select hardwoods	1	0	0	0	0	3	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	874	201	253	723	759	1,318	1,265	1,818	0	1,259	0	0	0
Total all species	1,011	245	280	809	866	1,469	1,551	1,868	0	2,360	0	0	0
Number of plots	69	8	9	6	16	17	10	2	0	1	0	0	0
Standard error[3]	81	75	73	157	88	142	151	311	0	R	0	0	0
Average basal area	76	24	38	81	72	99	103	105	0	165	0	0	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 60.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Minnesota, 1977[1]

Balsam poplar forest type - All site index classes

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years) 0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	1	0	0	0	0	1	3	0	3	0	0	0	0
Red pine	1	0	0	2	0	0	4	0	0	0	0	0	0
Jack pine	2	1	0	0	0	6	3	4	0	0	0	0	0
White spruce	10	11	7	0	7	10	16	11	14	34	0	0	0
Black spruce	5	6	0	0	2	11	7	0	5	0	0	0	0
Balsam fir	72	13	7	17	52	126	114	114	140	86	0	0	0
Tamarack	8	0	5	0	1	8	18	26	13	28	0	0	0
Northern white-cedar	12	0	3	4	10	8	19	20	34	172	0	0	0
Other softwoods	0	0	0	0	0	1	0	0	0	0	0	0	0
Total	111	31	22	23	72	171	183	175	209	319	0	0	0
Hardwoods:													
Select white oaks	3	2	4	11	2	1	6	2	5	0	0	0	0
Select red oaks	2	0	0	0	1	2	1	0	21	0	0	0	0
Other red oaks	0	0	0	0	0	1	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	32	0	0	0
Hard maple	3	0	0	2	5	3	2	5	7	0	0	0	0
Soft maple	1	0	0	0	2	1	1	0	0	0	0	0	0
Ash	39	11	4	22	21	50	35	86	134	216	166	0	0
Balsam poplar	409	120	101	238	397	615	579	641	482	570	869	0	0
Paper birch	45	6	9	24	56	65	46	58	104	157	0	0	0
Bigtooth aspen	1	0	0	0	0	1	2	0	5	0	0	0	0
Quaking aspen	111	38	44	92	139	151	122	208	63	68	0	0	0
Basswood	4	3	0	2	3	5	7	2	4	39	0	0	0
Elm	25	6	14	10	22	31	30	43	50	101	64	0	0
Select hardwoods	0	0	0	0	0	1	0	0	0	0	0	0	0
Other hardwoods	0	0	1	0	1	0	1	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	643	186	177	400	650	926	831	1,045	874	1,183	1,098	0	0
Total all species	753	217	199	423	722	1,097	1,014	1,220	1,083	1,502	1,098	0	0
Number of plots	389	45	55	31	65	85	56	28	18	5	1	0	0
Standard error[3]	32	29	27	68	57	72	71	135	116	291	R	0	0
Average basal area	67	26	37	56	70	87	76	91	90	113	120	0	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 61.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Aspen-Birch Unit, Minnesota, 1977[1]

Jack pine forest type - Site index class 0-50

(In cubic feet per acre)

		Stand-age class (years)											
Species	Average[2]	0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	54	0	31	0	0	569	0	14	0	0	209	0	0
Red pine	8	0	0	0	0	0	0	0	0	65	71	0	0
Jack pine	393	0	0	234	1,529	0	347	462	0	639	335	503	0
White spruce	4	0	0	0	0	0	0	0	0	0	0	29	0
Black spruce	79	0	0	0	0	0	0	51	0	457	57	272	0
Balsam fir	15	0	0	0	0	0	0	42	0	77	0	0	0
Tamarack	0	0	0	0	0	0	0	0	0	0	0	0	0
Northern white-cedar	0	0	0	0	0	0	0	0	0	0	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	553	0	31	234	1,529	569	347	569	0	1,238	672	804	0
Hardwoods:													
Select white oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Select red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Soft maple	7	0	0	0	0	0	52	0	0	0	0	0	0
Ash	0	0	0	0	0	0	0	0	0	0	0	0	0
Balsam poplar	0	0	0	0	0	0	0	0	0	0	0	0	0
Paper birch	36	0	119	0	0	0	0	34	0	142	0	88	0
Bigtooth aspen	0	0	0	0	0	0	0	0	0	0	0	0	0
Quaking aspen	103	82	0	44	0	262	105	204	0	49	0	55	0
Basswood	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	0	0	0	0	0	0	0	0	0	0	0	0	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	146	82	119	44	0	262	157	238	0	191	0	143	0
Total all species	699	82	150	278	1,529	832	504	807	0	1,428	672	947	0
Number of plots	16	2	1	1	1	1	2	4	0	1	1	2	0
Standard error[3]	114	82	R	R	R	R	132	160	0	R	R	163	0
Average basal area	74	36	23	45	130	70	88	74	0	128	60	90	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 62.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Aspen-Birch Unit, Minnesota, 1977[1]

Jack pine forest type - Site index class 51-60

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)										
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	1	0	0	0	0	3	0	0	0	0	0	0	0
Red pine	40	0	0	0	0	21	67	101	0	0	0	0	0
Jack pine	1,312	660	0	0	875	799	1,868	1,999	1,094	1,479	495	0	0
White spruce	7	0	0	0	0	8	8	0	115	0	0	0	0
Black spruce	95	0	0	0	0	85	17	256	0	135	627	0	0
Balsam fir	23	0	0	0	15	42	20	12	45	71	0	0	0
Tamarack	0	0	0	0	0	0	0	0	0	0	0	0	0
Northern white-cedar	0	0	0	0	0	0	0	0	0	0	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	1,477	660	0	0	890	958	1,980	2,368	1,254	1,684	1,122	0	0
Hardwoods:													
Select white oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Select red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Soft maple	6	0	0	0	0	0	23	0	0	0	0	0	0
Ash	0	0	0	0	0	0	0	0	0	0	0	0	0
Balsam poplar	0	0	0	0	0	0	0	0	0	0	0	0	0
Paper birch	17	0	0	0	0	7	6	0	0	50	439	0	0
Bigtooth aspen	0	0	0	0	0	0	0	0	0	0	0	0	0
Quaking aspen	155	111	0	0	0	217	76	386	53	0	0	0	0
Basswood	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	0	0	0	0	0	0	0	0	0	0	0	0	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	178	111	0	0	0	224	104	386	53	50	439	0	0
Total all species	1,655	771	0	0	890	1,182	2,084	2,755	1,307	1,734	1,561	0	0
Number of plots	37	5	0	0	4	8	9	7	1	2	1	0	0
Standard error[3]	209	577	0	0	158	275	443	583	R	158	R	0	0
Average basal area	91	61	0	0	66	77	102	119	112	122	90	0	0

[1] Table may not add to totals due to rounding. Forest type definitions and soecies list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 63.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Aspen-Birch Unit, Minnesota, 1977[1]

Jack pine forest type - Site index class 61-70

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)										
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	0	0	0	0	0	0	0	0	0	0	0	0	0
Red pine	7	0	0	0	34	0	0	0	0	0	0	0	0
Jack pine	897	0	0	412	686	1,315	1,277	972	0	968	0	0	0
White spruce	16	0	0	0	76	0	0	0	0	0	0	0	0
Black spruce	70	0	0	0	80	41	164	0	0	0	0	0	0
Balsam fir	63	0	0	212	132	32	0	0	0	0	0	0	0
Tamarack	0	0	0	0	0	0	0	0	0	0	0	0	0
Northern white-cedar	0	0	0	0	0	0	0	0	0	0	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	1,054	0	0	624	1,008	1,389	1,441	972	0	968	0	0	0
Hardwoods:													
Select white oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Select red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Soft maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	0	0	0	0	0	0	0	0	0	0	0	0	0
Balsam poplar	0	0	0	0	0	0	0	0	0	0	0	0	0
Paper birch	41	0	0	0	12	39	115	0	0	0	0	0	0
Bigtooth aspen	0	0	0	0	0	0	0	0	0	0	0	0	0
Quaking aspen	217	50	0	0	134	345	265	126	0	713	0	0	0
Basswood	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	0	0	0	0	0	0	0	0	0	0	0	0	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	258	50	0	0	145	384	380	126	0	713	0	0	0
Total all species	1,312	50	0	624	1,153	1,773	1,821	1,098	0	1,681	0	0	0
Number of plots	14	1	0	2	3	2	4	1	0	1	0	0	0
Standard error[3]	183	R	0	258	321	163	297	R	0	R	0	0	0
Average basal area	95	8	0	61	112	113	115	71	0	110	0	0	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 64.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Aspen-Birch Unit, Minnesota, 1977[1]

Jack pine forest type - All site index classes

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years) 0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	12	0	31	0	0	35	0	5	0	0	105	0	0
Red pine	26	0	0	0	35	10	40	59	0	16	35	0	0
Jack pine	1,073	413	0	353	858	1,211	1,507	1,401	1,094	1,141	415	503	0
White spruce	9	0	0	0	34	7	5	0	115	0	0	29	0
Black spruce	88	0	0	0	24	93	54	167	0	182	342	272	0
Balsam fir	29	0	0	141	46	36	12	21	45	55	0	0	0
Tamarack	0	0	0	0	0	0	0	0	0	0	0	0	0
Northern white-cedar	0	0	0	0	0	0	0	0	0	0	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	1,237	413	31	494	997	1,392	1,618	1,652	1,254	1,393	897	804	0
Hardwoods:													
Select white oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Select red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Soft maple	5	0	0	0	0	2	21	0	0	0	0	0	0
Ash	0	0	0	0	0	0	0	0	0	0	0	0	0
Balsam poplar	0	0	0	0	0	0	0	0	0	0	0	0	0
Paper birch	27	0	119	0	11	17	34	11	0	60	220	88	0
Bigtooth aspen	0	0	0	0	0	0	0	0	0	0	0	0	0
Quaking aspen	160	96	0	15	108	212	130	304	53	190	0	55	0
Basswood	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	0	0	0	0	0	0	0	0	0	0	0	0	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	192	96	119	15	120	231	185	315	53	251	220	143	0
Total all species	1,429	509	150	509	1,116	1,623	1,803	1,967	1,307	1,644	1,116	947	0
Number of plots	75	8	1	3	10	17	15	12	1	4	2	2	0
Standard error[3]	125	368	R	189	136	219	303	436	R	98	445	163	0
Average basal area	90	48	23	56	90	93	104	100	112	120	75	90	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 65.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Aspen-Birch Unit, Minnesota, 1977[1]

Red pine forest type - Site index class 51-60

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years) 0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	203	0	0	0	42	344	205	154	219	393	519	0	0
Red pine	1,135	789	80	0	1,097	1,176	372	908	2,084	1,353	1,256	0	0
Jack pine	114	0	30	0	546	94	0	0	93	143	0	0	0
White spruce	22	0	0	0	54	0	0	0	40	0	149	0	0
Black spruce	12	0	0	0	0	0	0	247	0	0	0	0	0
Balsam fir	30	0	12	0	0	64	93	92	43	0	0	0	0
Tamarack	0	0	0	0	0	0	0	0	0	0	0	0	0
Northern white-cedar	8	0	0	0	0	0	0	69	19	0	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	1,524	789	122	0	1,738	1,678	669	1,470	2,497	1,889	1,923	0	0
Hardwoods:													
Select white oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Select red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Soft maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	0	0	0	0	0	0	0	0	0	0	0	0	0
Balsam poplar	0	0	0	0	0	0	0	0	0	0	0	0	0
Paper birch	68	0	0	0	0	122	0	0	203	19	0	0	0
Bigtooth aspen	4	0	0	0	0	0	0	0	15	0	0	0	0
Quaking aspen	105	154	0	0	0	67	138	59	170	266	0	0	0
Basswood	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	0	0	0	0	0	0	0	0	0	0	0	0	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	177	154	0	0	0	189	138	59	388	285	0	0	0
Total all species	1,701	943	122	0	1,738	1,867	807	1,529	2,885	2,174	1,923	0	0
Number of plots	21	1	4	0	2	3	1	1	5	3	1	0	0
Standard error[3]	277	R	70	0	545	251	R	R	711	555	R	0	0
Average basal area	109	75	28	0	151	157	79	105	149	89	142	0	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 66.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Aspen-Birch Unit, Minnesota, 1977[1]

Red pine forest type - All site index classes

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	146	0	0	0	26	270	217	51	219	279	519	0	0
Red pine	1,134	789	64	792	1,205	969	1,856	494	2,084	1,328	1,256	686	0
Jack pine	86	0	24	0	182	107	48	62	93	102	0	0	0
White spruce	41	0	0	62	101	8	54	60	40	0	149	0	0
Black spruce	15	0	0	0	19	16	0	82	0	18	0	0	0
Balsam fir	39	0	10	0	81	46	39	31	43	0	0	184	0
Tamarack	0	0	0	0	0	0	0	0	0	0	0	0	0
Northern white-cedar	4	0	0	0	0	0	0	23	19	0	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	1,465	789	98	854	1,613	1,417	2,212	804	2,497	1,727	1,923	870	0
Hardwoods:													
Select white oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Select red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Soft maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	0	0	0	0	0	0	0	0	0	0	0	0	0
Balsam poplar	0	0	0	0	0	0	0	0	0	0	0	0	0
Paper birch	59	0	0	0	85	116	0	0	203	12	0	0	0
Bigtooth aspen	2	0	0	0	0	0	0	0	15	0	0	0	0
Quaking aspen	103	154	0	246	41	91	115	20	170	239	0	197	0
Basswood	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	0	0	0	0	0	0	0	0	0	0	0	0	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	164	154	0	246	126	206	115	20	388	250	0	197	0
Total all species	1,629	943	98	1,100	1,739	1,623	2,327	823	2,885	1,977	1,923	1,067	0
Number of plots	38	1	5	1	7	5	4	3	5	5	1	1	0
Standard error[3]	199	R	60	R	318	244	871	353	711	496	R	R	0
Average basal area	106	75	30	120	126	133	124	81	149	90	142	71	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 67.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Aspen-Birch Unit, Minnesota, 1977[1]

White pine forest type - Site index class 0-50

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	684	0	0	0	0	0	0	860	558	352	736	913	0
Red pine	156	0	0	0	0	0	0	385	354	122	48	0	0
Jack pine	106	0	0	0	0	0	0	236	534	29	0	0	0
White spruce	124	0	0	0	0	0	0	113	0	0	254	0	0
Black spruce	24	0	0	0	0	0	0	0	0	36	43	0	0
Balsam fir	71	0	0	0	0	0	0	25	0	0	156	38	0
Tamarack	0	0	0	0	0	0	0	0	0	0	0	0	0
Northern white-cedar	15	0	0	0	0	0	0	0	0	0	38	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	1,181	0	0	0	0	0	0	1,618	1,446	538	1,275	951	0
Hardwoods:													
Select white oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Select red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Soft maple	11	0	0	0	0	0	0	26	0	0	13	0	0
Ash	6	0	0	0	0	0	0	28	0	0	0	0	0
Balsam poplar	0	0	0	0	0	0	0	0	0	0	0	0	0
Paper birch	42	0	0	0	0	0	0	0	0	102	55	0	0
Bigtooth aspen	4	0	0	0	0	0	0	0	0	18	0	0	0
Quaking aspen	201	0	0	0	0	0	0	183	1,175	57	88	0	0
Basswood	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	0	0	0	0	0	0	0	0	0	0	0	0	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	263	0	0	0	0	0	0	236	1,175	178	156	0	0
Total all species	1,444	0	0	0	0	0	0	1,855	2,622	715	1,431	951	0
Number of plots	10	0	0	0	0	0	0	2	1	2	4	1	0
Standard error[3]	245	0	0	0	0	0	0	335	R	28	424	R	0
Average basal area	110	0	0	0	0	0	0	124	80	90	119	112	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 68.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Aspen-Birch Unit, Minnesota, 1977[1/]

White pine forest type - All site index classes

(In cubic feet per acre)

Species	Average[2/]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	623	843	120	0	0	750	0	769	644	352	614	913	0
Red pine	86	0	163	0	0	0	0	256	118	122	31	0	0
Jack pine	69	0	0	0	0	0	0	283	178	29	0	0	0
White spruce	118	0	0	0	0	0	0	244	114	0	156	0	0
Black spruce	27	0	62	0	0	0	0	0	0	36	49	0	0
Balsam fir	38	0	0	0	0	0	0	17	0	0	80	38	0
Tamarack	0	0	0	0	0	0	0	0	0	0	0	0	0
Northern white-cedar	7	0	0	0	0	0	0	0	0	0	17	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	969	843	345	0	0	750	0	1,569	1,054	538	947	951	0
Hardwoods:													
Select white oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Select red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Soft maple	15	0	0	0	0	0	0	18	51	0	11	0	0
Ash	3	0	0	0	0	0	0	18	0	0	0	0	0
Balsam poplar	0	0	0	0	0	0	0	0	0	0	0	0	0
Paper birch	37	0	0	0	0	0	0	53	0	102	45	0	0
Bigtooth aspen	2	0	0	0	0	0	0	0	0	18	0	0	0
Quaking aspen	154	0	0	0	0	0	0	258	545	57	78	0	0
Basswood	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	0	0	0	0	0	0	0	0	0	0	0	0	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	209	0	0	0	0	0	0	347	596	178	135	0	0
Total all species	1,179	843	345	0	0	750	0	1,916	1,650	715	1,082	951	0
Number of plots	21	1	1	0	0	1	0	3	3	2	9	1	0
Standard error[3/]	148	R	R	0	0	R	0	203	490	28	225	R	0
Average basal area	102	120	34	0	0	120	0	119	108	90	98	112	0

[1/] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2/] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3/] R indicates that there was an insufficient number of plots to compute the standard error.

Table 69.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Aspen-Birch Unit, Minnesota, 1977[1]

Black spruce forest type - Site index class 0-50

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years) 0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	2	0	3	1	0	3	6	1	1	10	0	0	0
Red pine	2	0	0	0	0	6	0	0	0	24	0	0	0
Jack pine	14	18	3	1	10	0	52	32	23	10	20	0	0
White spruce	6	41	1	1	5	10	8	5	12	0	15	0	0
Black spruce	371	29	143	166	189	416	434	663	581	625	674	433	1,016
Balsam fir	22	0	10	4	18	33	45	40	56	18	1	0	0
Tamarack	34	14	9	15	21	16	43	57	68	49	60	92	61
Northern white-cedar	11	3	0	1	11	16	1	10	24	52	0	16	26
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	462	105	170	189	254	499	590	808	766	788	771	541	1,103
Hardwoods:													
Select white oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Select red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Soft maple	0	0	0	0	0	0	0	0	1	0	0	0	0
Ash	2	0	0	0	0	10	0	3	5	0	0	0	0
Balsam poplar	2	0	1	0	1	1	5	0	4	3	0	0	0
Paper birch	7	0	6	2	1	7	9	12	22	11	9	0	0
Bigtooth aspen	0	0	0	0	0	0	0	0	0	1	0	0	0
Quaking aspen	28	0	28	5	17	13	92	46	40	29	16	0	0
Basswood	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	0	0	0	0	0	0	0	0	0	0	0	0	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	38	0	36	7	20	31	106	61	72	44	25	0	0
Total all species	500	105	206	196	273	530	696	869	838	833	796	541	1,103
Number of plots	422	9	42	77	70	43	45	31	40	24	25	9	7
Standard error	24	42	36	22	34	75	91	89	80	117	107	87	225
Average basal area	73	38	45	56	66	77	85	94	91	95	96	75	106

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

Table 70.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Aspen-Birch Unit, Minnesota, 1977[1]

Black spruce forest type - Site index class 51-60

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	26	0	0	0	0	0	0	69	220	0	0	0	0
Red pine	8	0	0	0	0	0	0	0	92	0	0	0	0
Jack pine	35	62	64	0	0	44	122	0	0	0	0	0	0
White spruce	2	0	0	0	0	0	0	0	22	0	0	0	0
Black spruce	636	281	109	326	367	654	826	996	1,472	1,585	908	0	0
Balsam fir	40	46	19	11	32	30	77	14	95	0	136	0	0
Tamarack	28	0	0	18	52	28	0	18	140	0	0	0	0
Northern white-cedar	8	0	0	0	0	0	26	39	0	0	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	783	390	191	355	452	755	1,050	1,136	2,042	1,585	1,044	0	0
Hardwoods:													
Select white oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Select red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Soft maple	1	0	0	0	5	0	0	0	0	0	0	0	0
Ash	2	0	0	0	0	0	14	0	0	0	0	0	0
Balsam poplar	2	0	0	0	0	0	13	0	0	0	0	0	0
Paper birch	12	0	0	0	8	0	18	72	0	0	0	0	0
Bigtooth aspen	0	0	0	0	0	0	0	0	0	0	0	0	0
Quaking aspen	45	0	0	74	61	59	124	14	0	0	0	0	0
Basswood	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	0	0	0	0	0	0	0	0	0	0	0	0	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	62	0	0	74	74	59	169	85	0	0	0	0	0
Total all species	845	390	191	429	526	814	1,219	1,222	2,042	1,585	1,044	0	0
Number of plots	36	2	5	4	6	5	5	4	3	1	1	0	0
Standard error[3]	110	98	152	161	160	90	157	344	511	R	R	0	0
Average basal area	82	69	42	70	67	92	112	86	115	105	112	0	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 71.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Aspen-Birch Unit, Minnesota, 1977[1]

Black spruce forest type - All site index classes

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	4	0	2	1	0	3	5	9	17	10	0	0	0
Red pine	2	0	0	0	0	5	0	0	6	23	0	0	0
Jack pine	16	26	9	1	9	4	59	27	22	9	20	0	0
White spruce	6	34	1	1	5	8	9	4	13	0	14	0	0
Black spruce	392	75	143	174	203	445	466	703	643	663	683	433	1,016
Balsam fir	25	8	14	4	19	42	48	36	59	17	6	0	0
Tamarack	34	11	8	15	23	22	42	54	73	48	58	92	61
Northern white-cedar	10	2	0	1	10	13	3	13	22	50	0	16	26
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	489	156	178	197	269	542	632	845	855	820	781	541	1,103
Hardwoods:													
Select white oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Select red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Soft maple	0	0	0	0	0	0	0	0	1	0	0	0	0
Ash	2	0	0	0	0	8	1	3	4	0	0	0	0
Balsam poplar	2	0	1	0	1	1	6	0	4	3	0	0	0
Paper birch	9	0	8	2	2	10	17	18	20	11	9	0	0
Bigtooth aspen	0	0	0	0	0	0	0	0	0	1	0	0	0
Quaking aspen	30	0	24	9	20	25	96	41	37	28	16	0	0
Basswood	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	0	0	0	0	0	0	0	0	0	0	0	0	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	42	0	33	11	24	45	120	62	67	43	24	0	0
Total all species	531	156	211	208	293	587	753	907	922	863	805	541	1,103
Number of plots	466	11	49	81	76	51	52	36	43	25	26	9	7
Standard error	24	50	34	23	35	68	83	86	93	116	103	87	225
Average basal area	74	44	45	56	66	78	87	93	93	95	96	75	106

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

Table 72.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Aspen-Birch Unit, Minnesota, 1977[1]

Balsam fir forest type - Site index class 0-50

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)										
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:												
White pine	16	0	30	8	11	10	16	8	65	0	36	0	0
Red pine	10	0	18	0	20	0	6	20	42	0	0	0	0
Jack pine	9	6	26	0	5	2	11	17	0	0	29	0	0
White spruce	25	4	24	0	14	31	20	52	29	0	103	0	0
Black spruce	66	94	30	43	29	97	66	65	111	44	84	0	0
Balsam fir	238	32	134	58	173	311	337	363	215	215	380	0	0
Tamarack	6	6	4	15	0	14	3	2	0	0	0	0	0
Northern white-cedar	51	34	16	52	83	36	63	38	94	33	55	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	421	175	282	176	336	501	522	565	558	293	688	0	0
Hardwoods:												
Select white oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Select red oaks	0	0	0	0	3	0	0	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	1	0	0	0	0	3	0	0	0	0	0	0	0
Hard maple	0	0	0	0	0	0	0	0	3	0	0	0	0
Soft maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	10	0	2	6	19	8	12	9	0	0	61	0	0
Balsam poplar	8	0	3	6	16	16	7	6	5	0	0	0	0
Paper birch	70	33	22	33	68	78	100	108	47	61	89	0	0
Bigtooth aspen	1	0	0	0	4	0	2	0	0	0	0	0	0
Quaking aspen	63	5	32	27	34	63	128	88	40	0	42	0	0
Basswood	0	0	0	0	0	0	0	2	0	0	0	0	0
Elm	1	0	0	0	2	0	4	0	0	0	0	0	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	154	39	59	73	146	169	252	214	96	61	191	0	0
Total all species	575	214	341	249	482	670	774	779	654	354	878	0	0
Number of plots	174	9	17	22	20	32	36	20	11	2	5	0	0
Standard error	28	65	53	34	63	63	54	79	83	131	273	0	0
Average basal area	77	23	53	59	75	88	96	100	76	45	77	0	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

Table 73.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Aspen-Birch Unit, Minnesota, 1977[1]

Balsam fir forest type - Site index class 51-60

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years) 0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	23	0	24	0	0	7	39	74	0	0	0	636	0
Red pine	23	0	22	10	17	35	28	0	0	0	0	0	0
Jack pine	12	0	9	0	7	11	14	18	335	0	0	0	0
White spruce	54	94	12	0	56	37	62	112	0	356	0	284	0
Black spruce	51	0	12	86	74	53	52	28	69	0	0	103	0
Balsam fir	367	89	113	198	305	438	406	562	95	441	463	461	0
Tamarack	6	31	0	8	2	2	8	33	0	0	0	0	0
Northern white-cedar	53	11	26	7	44	50	72	58	0	0	753	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	589	226	218	308	505	632	680	883	499	797	1,215	1,484	0
Hardwoods:													
Select white oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Select red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	1	0	10	0	0	0	0	0	0	0	0	0	0
Soft maple	3	0	0	0	0	2	8	0	0	0	0	97	0
Ash	1	15	0	0	0	2	0	0	0	0	0	0	0
Balsam poplar	22	0	4	25	20	23	32	0	0	142	0	0	0
Paper birch	106	31	67	73	95	113	136	87	108	148	238	0	0
Bigtooth aspen	3	0	0	0	0	2	8	0	0	0	0	0	0
Quaking aspen	110	0	28	130	160	116	84	213	60	0	0	230	0
Basswood	0	0	0	4	0	0	0	0	0	0	0	0	0
Elm	0	0	0	0	0	1	0	0	0	0	0	0	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	247	47	109	232	275	259	268	300	168	290	238	327	0
Total all species	835	272	327	540	780	891	949	1,184	666	1,087	1,454	1,811	0
Number of plots	144	4	12	8	22	50	33	10	1	2	1	1	0
Standard error[3]	42	128	49	116	104	62	99	155	R	80	R	R	0
Average basal area	85	55	50	77	83	92	88	100	64	106	94	120	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 74.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Aspen-Birch Unit, Minnesota, 1977[1]

Balsam fir forest type - Site index class 61-70

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	19	0	0	0	6	21	0	0	122	148	0	0	0
Red pine	41	0	0	0	8	9	150	0	267	0	0	0	0
Jack pine	4	0	0	0	5	7	0	0	0	0	0	0	0
White spruce	69	0	88	21	31	15	99	329	211	247	0	0	0
Black spruce	49	73	0	49	31	46	29	252	0	0	0	0	0
Balsam fir	525	330	183	343	371	630	847	459	169	143	0	0	0
Tamarack	6	0	0	0	0	15	0	0	0	0	0	0	0
Northern white-cedar	46	0	156	147	22	54	0	69	0	41	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	757	403	427	560	473	796	1,125	1,109	769	579	0	0	0
Hardwoods:													
Select white oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Select red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	2	0	0	0	0	7	0	0	0	0	0	0	0
Hard maple	5	0	0	0	0	8	0	44	0	0	0	0	0
Soft maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	12	0	0	47	0	15	7	0	33	0	0	0	0
Balsam poplar	30	0	0	17	6	28	31	208	0	0	0	0	0
Paper birch	106	0	0	16	148	107	192	80	36	101	0	0	0
Bigtooth aspen	0	0	0	0	0	0	0	0	0	0	0	0	0
Quaking aspen	164	405	0	49	93	182	142	375	37	211	0	0	0
Basswood	1	0	0	0	0	4	0	0	0	0	0	0	0
Elm	2	0	0	0	0	7	0	0	0	0	0	0	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	323	405	0	130	247	357	371	706	106	312	0	0	0
Total all species	1,080	808	427	690	720	1,153	1,496	1,815	874	891	0	0	0
Number of plots	52	3	2	4	8	19	9	3	2	2	0	0	0
Standard error	77	168	166	255	96	87	192	630	433	339	0	0	0
Average basal area	96	95	105	69	73	94	138	124	59	64	0	0	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

Table 75.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Aspen-Birch Unit, Minnesota, 1977[1]

Balsam fir forest type - All site index classes

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	19	0	26	5	5	10	26	27	69	49	30	636	0
Red pine	19	0	18	2	16	18	31	12	71	0	0	0	0
Jack pine	9	3	18	0	6	7	11	15	24	0	24	0	0
White spruce	45	37	23	4	35	33	58	95	53	201	86	284	0
Black spruce	57	64	21	52	48	63	59	71	92	15	70	103	0
Balsam fir	334	95	129	124	263	460	424	432	200	266	394	461	0
Tamarack	6	10	2	11	1	8	5	11	0	0	0	0	0
Northern white-cedar	51	19	29	51	61	45	61	47	74	25	171	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	542	228	267	249	436	645	673	711	584	556	776	1,484	0
Hardwoods:													
Select white oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Select red oaks	0	0	0	0	1	0	0	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	1	0	0	0	0	2	0	0	0	0	0	0	0
Hard maple	1	0	4	0	0	1	0	4	2	0	0	0	0
Soft maple	1	0	0	0	0	1	3	0	0	0	0	97	0
Ash	7	3	1	9	7	6	6	5	5	0	50	0	0
Balsam poplar	16	0	3	12	16	22	20	22	4	47	0	0	0
Paper birch	89	39	38	39	95	101	124	99	50	104	114	0	0
Bigtooth aspen	1	0	0	0	2	1	4	0	0	0	0	0	0
Quaking aspen	98	78	28	53	100	118	114	152	41	70	35	230	0
Basswood	1	0	0	1	0	2	0	1	0	0	0	0	0
Elm	1	0	0	0	1	2	2	0	0	0	0	0	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	216	120	74	114	221	257	273	285	102	221	199	327	0
Total all species	758	349	341	363	658	901	946	996	686	777	974	1,811	0
Number of plots	380	18	31	35	51	104	81	33	14	6	6	1	0
Standard error[3]	26	70	35	51	56	46	57	98	82	169	243	R	0
Average basal area	83	42	55	64	79	92	98	102	73	71	80	120	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 76.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Aspen-Birch Unit, Minnesota, 1977[1]

Northern white-cedar forest type - Site index class 0-50

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	10	0	0	0	0	0	12	0	3	20	0	10	31
Red pine	6	0	0	0	32	0	0	32	0	0	0	0	6
Jack pine	2	0	0	0	0	0	0	20	0	0	0	0	0
White spruce	7	0	0	0	0	7	8	0	3	1	0	27	15
Black spruce	85	0	0	8	97	138	125	62	101	110	108	70	72
Balsam fir	69	0	9	18	41	23	65	53	59	84	127	102	69
Tamarack	14	0	4	0	14	17	15	20	23	5	24	10	13
Northern white-cedar	503	139	132	134	179	220	400	367	403	692	451	733	832
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	696	139	145	161	363	406	625	554	592	912	709	952	1,038
Hardwoods:													
Select white oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Select red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	2	0	0	0	0	0	0	0	1	0	0	0	13
Hard maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Soft maple	0	0	0	0	0	0	0	0	0	2	0	0	0
Ash	22	0	7	0	0	0	7	19	18	5	14	5	90
Balsam poplar	9	0	12	0	0	0	2	3	1	21	34	10	8
Paper birch	50	0	16	11	20	6	15	50	35	61	52	100	75
Bigtooth aspen	1	0	0	0	0	0	0	0	9	0	0	0	0
Quaking aspen	13	0	0	2	0	0	36	39	11	2	11	11	8
Basswood	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	0	0	0	0	0	0	0	0	2	0	0	0	1
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	98	0	34	12	20	6	60	112	77	91	111	126	194
Total all species	794	139	179	173	383	411	685	666	669	1,003	820	1,078	1,232
Number of plots	197	1	6	11	11	7	16	21	26	25	19	22	32
Standard error[3]	44	R	93	41	105	143	97	97	93	103	112	194	115
Average basal area	116	38	47	67	90	98	108	113	113	129	122	136	143

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 77.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Aspen-Birch Unit, Minnesota, 1977[1]

Northern white-cedar forest type - All site index classes

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	10	0	0	0	0	0	12	0	3	20	0	10	31
Red pine	6	0	0	0	27	0	0	31	0	0	0	0	6
Jack pine	2	0	0	0	0	5	0	18	0	0	0	0	0
White spruce	7	0	0	0	0	5	8	0	3	1	0	27	15
Black spruce	87	0	0	8	82	136	125	94	97	110	108	70	72
Balsam fir	71	0	9	18	53	82	65	55	57	84	127	102	69
Tamarack	14	0	4	0	12	23	15	17	22	5	24	10	13
Northern white-cedar	499	139	132	134	184	230	400	391	417	692	451	733	832
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	696	139	145	161	358	482	625	606	600	912	709	952	1,038
Hardwoods:													
Select white oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Select red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	3	0	0	0	0	0	0	0	6	0	0	0	13
Hard maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Soft maple	0	0	0	0	0	0	0	0	0	2	0	0	0
Ash	22	0	7	0	6	0	7	17	18	5	14	5	90
Balsam poplar	9	0	12	0	0	7	2	5	1	21	34	10	8
Paper birch	51	0	16	11	34	25	15	53	33	61	52	100	75
Bigtooth aspen	2	0	0	0	0	16	0	0	9	0	0	0	0
Quaking aspen	17	0	0	2	16	26	36	55	11	2	11	11	8
Basswood	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	0	0	0	0	0	0	0	0	2	0	0	0	1
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	104	0	34	12	55	74	60	130	79	91	111	126	194
Total all species	800	139	179	173	413	556	685	736	678	1,003	820	1,078	1,232
Number of plots	206	1	6	11	13	10	16	24	27	25	19	22	32
Standard error[3]	43	R	93	41	93	160	97	100	89	103	112	194	115
Average basal area	116	38	47	67	87	97	108	116	113	129	122	136	143

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 78.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Aspen-Birch Unit, Minnesota, 1977[1]

Tamarack forest type - Site index class 0-50

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)										
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:												
White pine	0	0	1	0	0	0	0	0	0	0	0	0	0
Red pine	0	0	0	0	0	0	0	0	0	0	0	0	0
Jack pine	1	0	0	4	0	0	0	6	0	0	0	0	0
White spruce	1	6	0	0	0	0	0	0	0	0	0	0	0
Black spruce	50	13	25	91	21	43	25	54	81	40	179	106	27
Balsam fir	8	11	10	0	5	0	16	25	9	0	0	4	0
Tamarack	232	77	84	107	44	318	152	401	297	537	298	612	528
Northern white-cedar	11	0	8	13	0	0	3	0	26	0	0	57	25
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	303	106	128	215	71	361	196	486	413	577	477	780	581
Hardwoods:												
Select white oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Select red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Soft maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	1	0	0	0	0	0	0	0	0	0	0	7	0
Balsam poplar	1	0	0	0	0	0	0	11	0	0	0	0	0
Paper birch	8	19	6	0	0	6	15	12	0	6	0	24	13
Bigtooth aspen	0	0	0	0	0	0	0	0	0	0	0	0	0
Quaking aspen	5	4	0	6	0	0	6	37	0	0	0	0	0
Basswood	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	0	0	0	0	0	0	0	0	0	0	0	0	0
Select hardwood-	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	15	23	6	6	0	6	21	59	0	6	0	31	13
Total all species	317	129	134	220	71	368	217	545	413	583	477	811	594
Number of plots	98	8	21	16	7	6	8	8	5	5	1	8	5
Standard error[3]	31	41	25	45	36	110	48	119	82	158	R	138	100
Average basal area	51	28	26	62	49	55	60	50	67	67	49	78	67

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 79.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Aspen-Birch Unit, Minnesota, 1977[1]

Tamarack forest type - Site index class 51-60

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	20	0	28	0	0	51	0	0	0	0	0	0	0
Red pine	0	0	0	0	0	0	0	0	0	0	0	0	0
Jack pine	4	0	17	0	0	0	0	0	0	0	0	0	0
White spruce	0	0	0	0	0	0	0	0	0	0	0	0	0
Black spruce	92	0	129	0	74	0	222	144	0	0	0	0	0
Balsam fir	21	0	0	0	0	22	84	0	0	0	0	0	0
Tamarack	348	79	195	0	121	306	561	969	587	0	0	0	0
Northern white-cedar	22	0	18	0	138	0	0	0	0	0	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	507	79	387	0	333	380	867	1,113	587	0	0	0	0
Hardwoods:													
Select white oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Select red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Soft maple	3	0	0	0	0	10	0	0	0	0	0	0	0
Ash	0	0	0	0	0	0	0	0	0	0	0	0	0
Balsam poplar	3	0	0	0	0	0	15	0	0	0	0	0	0
Paper birch	4	0	0	0	0	14	0	0	0	0	0	0	0
Bigtooth aspen	0	0	0	0	0	0	0	0	0	0	0	0	0
Quaking aspen	0	0	0	0	0	0	0	0	0	0	0	0	0
Basswood	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	0	0	0	0	0	0	0	0	0	0	0	0	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	9	0	0	0	0	25	15	0	0	0	0	0	0
Total all species	516	79	387	0	333	404	882	1,113	587	0	0	0	0
Number of plots	16	1	4	0	2	4	3	1	1	0	0	0	0
Standard error[3]	94	R	186	0	186	91	257	R	R	0	0	0	0
Average basal area	39	11	26	0	28	34	74	60	34	0	0	0	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 80.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Aspen-Birch Unit, Minnesota, 1977[1]

Tamarack forest type - All site index classes

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)										
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	3	0	5	0	0	20	0	0	0	0	0	0	0
Red pine	0	0	0	0	0	0	0	0	0	0	0	0	0
Jack pine	2	0	3	4	0	0	0	5	0	0	0	0	0
White spruce	0	5	0	0	0	0	0	0	0	0	0	0	0
Black spruce	55	11	42	91	31	26	78	64	68	40	179	106	27
Balsam fir	9	10	9	0	3	9	35	22	8	0	0	4	0
Tamarack	249	77	102	107	105	313	264	464	345	537	298	612	528
Northern white-cedar	13	0	9	13	25	0	2	0	21	0	0	57	25
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	331	103	170	215	165	369	379	556	442	577	477	780	581
Hardwoods:													
Select white oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Select red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Soft maple	0	0	0	0	0	4	0	0	0	0	0	0	0
Ash	1	0	0	0	0	0	0	0	0	0	0	7	0
Balsam poplar	1	0	0	0	0	0	4	9	0	0	0	0	0
Paper birch	8	17	5	0	0	10	11	11	0	6	0	24	13
Bigtooth aspen	0	0	0	0	0	0	0	0	0	0	0	0	0
Quaking aspen	4	3	0	6	0	0	4	33	0	0	0	0	0
Basswood	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	0	0	0	0	0	0	0	0	0	0	0	0	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	14	20	5	6	0	14	19	53	0	6	0	31	13
Total all species	345	124	174	220	165	382	398	608	442	583	477	811	594
Number of plots	116	9	25	16	11	10	11	9	6	5	1	8	5
Standard error[3]	29	37	39	45	53	72	116	122	73	158	R	138	100
Average basal area	49	26	26	62	41	47	64	51	61	67	49	78	67

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 81.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Aspen-Birch Unit, Minnesota, 1977[1]

White spruce forest type - All site index classes

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	19	0	0	0	100	0	33	0	0	0	0	0	0
Red pine	18	0	0	0	124	0	0	0	0	0	0	0	0
Jack pine	7	0	0	0	0	27	0	0	0	0	0	0	0
White spruce	329	0	28	374	188	453	339	986	56	884	948	593	0
Black spruce	22	0	0	0	0	53	63	0	0	0	0	0	0
Balsam fir	83	0	13	0	102	124	91	132	217	194	0	111	0
Tamarack	7	0	0	0	0	30	0	0	0	0	0	0	0
Northern white-cedar	35	0	0	0	44	0	0	0	799	0	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	520	0	41	374	558	686	526	1,117	1,071	1,078	948	705	0
Hardwoods:													
Select white oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Select red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Soft maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	0	0	0	0	0	0	0	0	0	0	0	0	0
Balsam poplar	2	0	0	0	0	9	0	0	0	0	0	0	0
Paper birch	108	23	14	64	204	119	108	0	180	0	390	181	0
Bigtooth aspen	0	0	0	0	0	0	0	0	0	0	0	0	0
Quaking aspen	109	0	0	75	114	232	84	0	0	576	0	0	0
Basswood	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	0	0	0	0	0	0	0	0	0	0	0	0	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	220	23	14	139	318	360	192	0	180	576	390	181	0
Total all species	740	23	55	513	876	1,046	718	1,117	1,251	1,654	1,338	886	0
Number of plots	28	4	3	1	4	7	4	1	1	1	1	1	0
Standard error[3]	115	23	55	R	328	260	62	R	R	R	R	R	0
Average basal area	63	5	19	71	86	84	69	94	98	79	70	64	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 82.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Aspen-Birch Unit, Minnesota, 1977[1]

Elm-ash-cottonwood forest type - Site index class 0-50

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	6	0	0	0	23	0	0	0	0	0	55	0	0
Red pine	2	0	0	0	0	18	0	0	0	0	0	0	0
Jack pine	3	0	0	0	0	0	0	0	0	23	0	0	0
White spruce	9	9	12	0	0	4	5	6	0	33	0	0	46
Black spruce	7	0	0	0	25	24	9	0	14	7	0	11	0
Balsam fir	63	14	60	0	35	64	83	93	185	50	69	75	61
Tamarack	3	8	21	0	0	0	0	0	0	0	0	0	0
Northern white-cedar	50	13	60	9	38	14	74	12	12	94	95	103	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	143	44	154	9	121	123	170	111	210	206	219	189	107
Hardwoods:													
Select white oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Select red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	1	0	0	0	0	0	7	0	0	0	0	0	0
Soft maple	6	0	0	0	11	10	4	9	0	20	0	0	0
Ash	292	68	141	105	86	282	282	498	327	513	414	412	171
Balsam poplar	19	10	14	6	0	20	6	7	122	24	38	8	0
Paper birch	45	16	34	0	46	125	28	103	39	22	25	30	76
Bigtooth aspen	1	0	0	18	0	0	0	0	0	0	0	0	0
Quaking aspen	28	8	0	7	17	16	34	117	115	11	19	18	21
Basswood	1	0	0	0	0	0	0	0	0	6	0	0	0
Elm	36	6	23	0	50	31	10	87	31	60	0	66	177
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	2	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	429	107	212	136	210	484	371	821	633	658	496	534	445
Total all species	571	151	366	145	331	608	541	932	844	863	715	724	552
Number of plots	90	10	9	5	5	10	11	8	4	11	8	7	2
Standard error	41	35	69	41	170	64	39	140	171	161	129	120	41
Average basal area	75	32	58	35	50	80	82	100	90	98	95	90	69

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

Table 83.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Aspen-Birch Unit, Minnesota, 1977[1]

Elm-ash-cottonwood forest type - Site index class 51-60

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	2	0	0	0	0	0	0	0	22	0	0	0	0
Red pine	0	0	0	0	0	0	0	0	0	0	0	0	0
Jack pine	0	0	0	0	0	0	0	0	0	0	0	0	0
White spruce	21	0	17	0	16	28	24	12	20	8	13	0	82
Black spruce	8	0	0	0	0	19	0	10	11	10	0	0	30
Balsam fir	88	0	48	155	27	76	107	142	59	65	81	200	83
Tamarack	0	0	0	0	0	0	0	0	0	0	0	0	0
Northern white-cedar	39	0	0	186	0	22	5	13	9	110	102	0	185
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	158	0	65	341	43	144	136	177	122	193	196	200	381
Hardwoods:													
Select white oaks	6	0	0	0	9	0	0	14	11	26	0	0	0
Select red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	11	0	0	0	0	0	0	6	8	0	99	0	13
Hard maple	3	0	0	0	0	0	0	16	7	0	0	0	0
Soft maple	5	0	0	0	44	0	4	4	7	0	7	0	0
Ash	510	276	34	0	113	357	478	759	396	1,076	622	257	632
Balsam poplar	44	54	0	0	24	82	5	35	102	25	58	29	68
Paper birch	42	0	43	0	10	33	40	52	69	0	93	32	65
Bigtooth aspen	0	0	0	0	0	0	0	0	0	0	0	0	0
Quaking aspen	41	32	14	53	47	50	27	18	26	30	87	34	125
Basswood	9	0	0	0	0	0	0	15	7	29	0	96	0
Elm	80	0	0	0	0	34	125	12	97	199	117	161	119
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	4	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	751	362	91	53	247	556	679	930	734	1,385	1,081	609	1,020
Total all species	909	362	156	393	289	700	815	1,108	856	1,578	1,277	809	1,401
Number of plots	72	2	4	1	4	10	13	11	8	7	6	2	4
Standard error[3]	69	286	61	R	86	67	114	132	113	328	223	106	421
Average basal area	85	40	29	49	54	69	78	102	88	116	118	71	112

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 84.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Aspen-Birch Unit, Minnesota, 1977[1]

Elm-ash-cottonwood forest type - All site index classes

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)										
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:												
White pine	4	0	0	0	13	0	0	0	14	0	32	0	0
Red pine	1	0	0	0	0	8	0	0	0	0	0	0	0
Jack pine	1	0	0	0	0	0	0	0	0	13	0	0	0
White spruce	15	6	13	0	7	27	16	9	12	22	6	0	60
Black spruce	7	0	0	0	14	20	4	5	11	8	0	9	17
Balsam fir	70	10	53	35	32	66	85	118	97	53	74	103	65
Tamarack	2	6	14	0	0	0	0	0	0	0	0	0	0
Northern white-cedar	42	9	38	33	21	17	33	12	9	95	98	80	113
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	142	31	117	67	86	140	138	144	144	190	209	192	255
Hardwoods:												
Select white oaks	3	0	0	0	4	0	0	8	7	15	0	0	0
Select red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	4	0	0	0	0	0	0	3	5	0	42	0	7
Hard maple	2	0	0	0	0	0	3	9	4	0	0	0	0
Soft maple	7	0	0	0	26	5	4	6	4	32	3	0	0
Ash	390	96	118	108	98	321	412	638	376	712	503	378	533
Balsam poplar	30	15	9	9	11	49	9	26	118	23	47	13	39
Paper birch	45	21	34	0	30	75	49	74	54	12	54	31	59
Bigtooth aspen	1	0	0	13	0	0	0	0	0	0	0	0	0
Quaking aspen	37	14	4	19	30	35	43	72	51	17	48	21	78
Basswood	5	0	0	0	0	0	9	8	4	14	0	21	0
Elm	64	4	15	0	28	31	78	49	104	116	50	87	263
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	2	1	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	589	150	180	148	226	515	606	893	731	943	747	551	977
Total all species	731	181	297	215	313	655	744	1,037	874	1,133	956	743	1,232
Number of plots	174	14	14	7	9	21	27	20	13	19	14	9	7
Standard error	39	45	53	53	97	44	72	91	86	167	139	94	294
Average basal area	79	31	47	44	52	73	81	101	91	103	105	86	100

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

Table 85.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Aspen-Birch Unit, Minnesota, 1977[1]

Maple-basswood forest type - Site index class 0-50

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	7	0	0	0	0	0	0	0	34	40	0	0	0
Red pine	2	0	0	0	0	0	0	0	15	0	0	0	0
Jack pine	4	0	0	0	0	23	0	0	0	0	0	0	0
White spruce	14	44	0	0	0	22	35	0	0	49	0	0	0
Black spruce	2	0	0	0	0	0	9	0	0	0	0	0	0
Balsam fir	60	0	0	0	90	18	39	0	0	419	435	43	78
Tamarack	0	0	0	0	0	0	0	0	0	0	0	0	0
Northern white-cedar	53	0	0	0	0	12	49	0	12	32	910	112	75
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	141	44	0	0	90	75	133	0	60	540	1,346	156	154
Hardwoods:													
Select white oaks	2	0	0	0	0	0	0	0	0	0	0	24	0
Select red oaks	20	0	0	0	0	0	13	0	135	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	66	0	45	0	140	12	100	121	116	59	0	42	12
Soft maple	30	90	14	52	0	32	12	93	20	61	0	41	0
Ash	48	0	51	207	0	9	14	19	37	225	0	154	0
Balsam poplar	15	0	0	0	25	0	0	0	27	83	86	0	38
Paper birch	74	123	59	0	87	103	47	123	147	21	0	59	19
Bigtooth aspen	0	0	0	0	0	0	0	0	0	0	0	0	0
Quaking aspen	97	76	88	0	15	18	0	187	10	0	2,265	0	133
Basswood	126	0	0	0	0	190	182	266	111	44	0	115	195
Elm	24	0	20	0	0	7	0	0	18	103	0	126	56
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	502	289	276	259	268	370	368	809	622	596	2,350	560	453
Total all species	643	333	276	259	358	446	501	809	682	1,136	3,696	716	607
Number of plots	38	1	2	2	3	6	7	3	5	2	1	3	3
Standard error[3]	97	R	33	52	42	132	85	173	137	42	R	226	262
Average basal area	83	41	62	51	74	56	81	108	108	113	190	91	71

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 86.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Aspen-Birch Unit, Minnesota. 1977[1]

Maple-basswood forest type - Site index class 51-60

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years) 0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	3	21	0	0	0	5	0	16	0	0	0	0	0
Red pine	0	0	0	0	0	0	0	0	0	0	0	0	0
Jack pine	12	0	0	0	0	0	0	145	0	0	0	33	0
White spruce	39	48	0	0	54	27	37	0	173	49	0	0	41
Black spruce	2	0	0	0	0	0	0	32	0	0	0	0	0
Balsam fir	60	0	75	71	73	70	83	33	81	18	41	38	29
Tamarack	1	0	0	0	0	0	0	15	0	0	0	0	0
Northern white-cedar	33	0	0	0	35	9	0	0	107	50	387	0	50
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	151	69	75	71	162	110	121	242	361	117	428	72	120
Hardwoods:													
Select white oaks	1	0	0	0	0	0	0	0	0	0	0	17	0
Select red oaks	18	36	33	0	34	18	7	0	0	75	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	36	0	0	0	0	56	0	0	219	0	92	0	0
Hard maple	185	0	69	0	78	166	213	0	357	333	347	61	551
Soft maple	30	0	0	106	62	37	0	161	0	46	0	0	0
Ash	60	0	0	0	37	84	42	292	43	24	0	14	63
Balsam poplar	34	0	0	0	0	8	0	0	0	246	0	160	0
Paper birch	121	57	67	47	162	203	129	69	26	55	91	187	0
Bigtooth aspen	5	0	0	0	0	14	11	0	0	0	0	0	0
Quaking aspen	54	0	43	0	75	83	31	42	0	96	0	121	0
Basswood	66	44	58	0	64	41	126	0	42	15	0	149	228
Elm	20	0	0	0	9	11	0	39	0	0	0	198	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	631	138	268	153	521	720	558	604	688	889	530	907	842
Total all species	781	207	344	225	683	830	679	846	1,049	1,006	959	979	962
Number of plots	59	2	4	1	4	15	11	4	5	5	2	4	2
Standard error[3]	49	69	81	R	87	78	98	258	98	190	182	313	163
Average basal area	93	45	64	41	78	98	95	77	127	109	75	108	111

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 87.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Aspen-Birch Unit, Minnesota, 1977[1]

Maple-basswood forest type - Site index class 61-70

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	53	0	0	0	0	23	0	894	72	0	249	0	0
Red pine	0	0	0	0	0	0	0	0	0	0	0	0	0
Jack pine	7	0	48	0	0	0	12	0	0	0	0	0	0
White spruce	22	0	20	0	0	0	14	0	69	0	0	64	46
Black spruce	10	0	69	0	0	21	0	0	0	0	0	0	0
Balsam fir	84	0	11	0	0	119	76	0	471	0	38	0	0
Tamarack	0	0	0	0	0	0	0	0	0	0	0	0	0
Northern white-cedar	20	0	0	0	0	0	0	0	27	0	0	40	202
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	195	0	149	0	0	163	102	894	639	0	287	103	248
Hardwoods:													
Select white oaks	3	0	0	0	0	0	0	0	0	77	0	9	0
Select red oaks	9	0	0	0	0	13	0	0	0	0	116	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	12	0	0	0	0	53	9	0	0	0	0	0	0
Hard maple	241	0	48	212	339	317	307	0	82	52	221	206	535
Soft maple	26	0	15	0	37	18	23	0	28	121	40	0	92
Ash	50	0	0	103	0	25	36	0	0	113	0	81	295
Balsam poplar	31	0	0	0	0	20	61	0	118	0	0	30	0
Paper birch	94	0	19	31	206	89	78	236	124	0	365	41	0
Bigtooth aspen	3	0	0	0	0	0	0	0	0	0	0	25	0
Quaking aspen	74	0	153	74	0	30	168	145	106	0	0	0	0
Basswood	123	0	0	0	58	21	284	0	53	407	344	140	0
Elm	122	0	0	0	0	0	88	0	403	392	0	193	512
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	786	0	234	420	639	586	1,054	381	915	1,161	1,087	726	1,435
Total all species	981	0	383	420	639	749	1,156	1,274	1,554	1,161	1,374	829	1,682
Number of plots	33	0	3	2	2	6	7	1	3	1	2	4	2
Standard error[3]	87	0	104	4	116	88	189	R	375	R	317	105	116
Average basal area	105	0	55	70	100	98	110	75	128	142	143	101	150

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 88.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Aspen-Birch Unit, Minnesota, 1977[1]

Maple-basswood forest type - All site index classes

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	16	14	0	0	0	8	0	96	30	9	100	0	0
Red pine	1	0	0	0	0	0	0	0	6	0	0	0	0
Jack pine	8	0	16	0	0	5	3	58	0	0	0	12	0
White spruce	26	46	7	0	22	19	30	0	83	38	0	23	25
Black spruce	4	0	23	0	0	5	2	13	0	0	0	0	0
Balsam fir	65	0	37	14	56	67	69	13	140	126	119	26	42
Tamarack	0	0	0	0	0	0	0	6	0	0	0	0	0
Northern white-cedar	34	0	0	0	14	7	14	0	52	35	337	45	104
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	155	61	83	14	92	110	119	186	309	208	555	106	171
Hardwoods:													
Select white oaks	3	0	0	0	0	1	0	14	0	9	0	16	0
Select red oaks	16	24	15	0	14	12	7	0	52	42	46	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	19	0	0	0	0	42	3	0	84	0	37	0	0
Hard maple	162	0	56	85	164	161	208	60	201	204	227	108	316
Soft maple	29	30	8	42	32	31	10	112	14	52	16	11	26
Ash	54	0	11	124	15	55	33	132	31	83	0	77	102
Balsam poplar	27	0	0	0	8	9	17	9	37	155	17	69	16
Paper birch	99	79	49	22	140	150	92	115	95	35	182	99	8
Bigtooth aspen	3	0	0	0	0	7	5	0	0	0	0	9	0
Quaking aspen	81	25	89	30	41	71	61	193	29	53	453	44	57
Basswood	105	30	26	0	37	67	186	142	71	149	138	136	149
Elm	61	0	4	0	4	7	25	60	100	261	0	177	170
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	659	188	259	302	454	612	644	837	715	1,044	1,117	747	845
Total all species	814	249	342	316	546	722	763	1,024	1,024	1,252	1,672	853	1,016
Number of plots	135	3	9	5	10	28	25	10	13	9	5	11	7
Standard error	45	58	47	46	63	60	87	146	135	220	527	126	212
Average basal area	93	44	61	56	80	88	95	97	120	114	125	101	105

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

Table 89.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Aspen-Birch Unit, Minnesota, 1977[1]

Aspen forest type - Site index class 0-50

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	6	4	0	0	0	13	8	0	0	0	0	138	0
Red pine	5	0	0	0	39	0	0	0	0	38	0	58	0
Jack pine	3	6	0	3	0	4	0	28	0	0	0	0	0
White spruce	11	0	0	0	0	14	18	94	0	0	0	46	0
Black spruce	17	6	14	0	0	21	26	53	18	0	0	181	0
Balsam fir	49	4	16	40	29	58	49	107	97	444	0	0	0
Tamarack	1	6	3	0	0	0	0	0	0	0	0	0	0
Northern white-cedar	16	4	4	0	0	0	22	203	25	0	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	108	30	37	43	68	109	123	484	141	482	0	424	0
Hardwoods:													
Select white oaks	2	0	0	0	0	13	0	0	0	0	0	0	0
Select red oaks	0	0	0	0	0	0	0	0	0	0	0	26	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	2	0	7	3	0	3	0	0	0	0	0	0	0
Soft maple	3	0	2	0	0	3	7	0	0	0	0	24	0
Ash	12	3	4	0	0	27	15	0	84	0	0	0	0
Balsam poplar	9	19	0	10	0	5	18	20	0	0	0	0	0
Paper birch	56	9	67	17	24	51	108	77	65	73	0	47	0
Bigtooth aspen	2	0	0	3	0	0	7	0	0	0	0	0	0
Quaking aspen	219	100	119	65	158	394	354	272	137	237	0	83	0
Basswood	2	0	0	0	5	9	0	0	9	0	0	0	0
Elm	4	6	2	0	0	11	5	0	0	0	0	0	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	1	0	0	0	0	4	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	312	138	201	98	187	520	515	369	294	310	0	180	0
Total all species	420	167	237	141	256	629	638	853	435	792	0	603	0
Number of plots	88	9	17	11	8	16	17	4	3	2	0	1	0
Standard error[3]	34	66	35	42	77	52	62	247	106	421	0	R	0
Average basal area	61	31	51	37	60	82	70	106	57	102	0	71	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 90.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Aspen-Birch Unit, Minnesota, 1977[1]

Aspen forest type - Site index class 51-60

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	11	0	2	4	9	24	9	21	4	77	0	0	0
Red pine	14	17	0	0	4	0	19	6	72	215	0	0	0
Jack pine	16	4	2	2	18	4	15	92	0	13	0	0	0
White spruce	24	9	8	6	44	7	54	30	69	0	0	0	0
Black spruce	20	3	5	12	27	21	8	84	44	12	0	0	0
Balsam fir	60	13	14	12	62	95	97	94	123	57	0	0	0
Tamarack	0	0	3	0	0	0	0	0	0	0	0	0	0
Northern white-cedar	7	3	19	2	3	3	8	7	4	0	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	153	49	54	39	169	154	211	333	316	373	0	0	0
Hardwoods:													
Select white oaks	2	3	0	0	0	4	0	6	0	0	0	0	0
Select red oaks	1	0	0	0	0	0	0	2	0	18	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	1	0	0	2	0	0	0	5	0	30	0	0	0
Soft maple	6	1	2	3	0	18	7	11	7	0	0	0	0
Ash	11	5	10	25	2	8	9	6	31	48	0	0	0
Balsam poplar	15	33	5	15	13	15	8	13	6	12	0	0	0
Paper birch	74	32	20	10	45	128	102	123	120	147	0	0	0
Bigtooth aspen	15	0	0	0	0	16	6	50	167	0	0	0	0
Quaking aspen	370	184	128	108	338	399	600	730	486	390	0	0	0
Basswood	2	0	3	6	0	3	0	2	0	0	0	0	0
Elm	6	3	3	0	0	6	6	3	39	44	0	0	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	501	261	172	169	398	596	739	950	854	691	0	0	0
Total all species	654	310	226	208	566	750	950	1,283	1,170	1,063	0	0	0
Number of plots	250	42	34	25	19	41	48	27	9	5	0	0	0
Standard error	37	79	25	26	78	46	84	127	174	312	0	0	0
Average basal area	64	28	41	45	64	73	83	99	98	92	0	0	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

Table 91.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Aspen-Birch Unit, Minnesota, 1977[1]

Aspen forest type - Site index class 61-70

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	12	7	14	3	5	6	22	9	0	188	0	0	0
Red pine	11	2	0	0	5	17	13	13	45	73	0	0	0
Jack pine	12	4	1	3	2	2	33	40	11	0	0	0	0
White spruce	25	6	14	14	18	10	24	72	97	64	329	0	0
Black spruce	18	25	0	7	7	5	19	42	97	59	0	0	0
Balsam fir	87	29	45	46	64	122	126	114	104	104	95	0	0
Tamarack	1	0	0	2	3	0	1	2	0	0	0	0	0
Northern white-cedar	12	3	4	5	3	10	14	64	0	61	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	178	76	78	79	107	173	253	356	354	550	424	0	0
Hardwoods:													
Select white oaks	2	1	1	2	4	4	1	0	0	0	0	0	0
Select red oaks	1	0	0	0	3	0	2	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	4	0	0	0	0
Hard maple	3	2	0	1	5	4	3	2	0	0	0	0	0
Soft maple	8	2	1	3	9	14	5	14	21	0	0	0	0
Ash	21	14	13	14	38	13	16	65	22	23	0	0	0
Balsam poplar	48	17	33	23	26	53	107	26	30	82	0	0	0
Paper birch	112	47	59	37	87	159	150	107	231	132	385	0	0
Bigtooth aspen	15	1	0	0	3	18	39	37	0	0	0	0	0
Quaking aspen	511	86	149	214	412	620	829	754	886	1,456	614	0	0
Basswood	5	6	3	0	11	3	1	0	29	0	0	0	0
Elm	5	1	4	8	1	3	14	2	8	0	0	0	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	1	0	0	0	4	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	731	176	262	301	601	892	1,167	1,006	1,230	1,692	999	0	0
Total all species	908	252	340	380	709	1,064	1,420	1,362	1,584	2,242	1,423	0	0
Number of plots	401	57	44	28	51	86	80	32	16	5	2	0	0
Standard error	38	32	31	48	55	76	93	144	165	386	879	0	0
Average basal area	77	39	55	55	74	88	98	97	103	141	94	0	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

Table 92.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Aspen-Birch Unit, Minnesota 1977[1]

Aspen forest type - Site index class 71-80

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years) 0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	9	2	10	3	13	4	15	3	0	67	40	0	0
Red pine	6	3	0	4	4	14	3	13	0	0	0	0	0
Jack pine	13	6	3	12	30	16	4	4	0	0	0	0	0
White spruce	18	9	8	14	18	23	24	17	0	0	23	0	0
Black spruce	17	12	6	11	17	14	22	38	105	0	28	0	0
Balsam fir	111	36	37	77	97	167	137	108	227	68	258	0	0
Tamarack	3	9	0	0	6	1	0	0	0	0	0	0	0
Northern white-cedar	7	2	2	0	1	14	6	0	0	385	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	183	80	67	121	184	252	210	184	332	520	349	0	0
Hardwoods:													
Select white oaks	2	0	0	0	1	0	7	12	0	0	0	0	0
Select red oaks	1	0	2	2	0	1	0	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	3	0	0	0	2	6	5	0	0	94	0	0	0
Soft maple	7	0	0	8	7	13	9	7	0	0	0	0	0
Ash	22	13	2	0	31	25	31	35	0	0	46	0	0
Balsam poplar	65	35	41	35	34	65	130	72	350	254	54	0	0
Paper birch	98	40	40	78	103	127	115	89	285	285	59	0	0
Bigtooth aspen	6	2	8	10	0	15	1	0	0	0	0	0	0
Quaking aspen	659	126	221	403	653	721	951	1,752	507	1,338	769	0	0
Basswood	4	6	0	0	2	6	6	0	0	0	0	0	0
Elm	10	8	6	2	1	12	13	40	0	0	55	0	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	876	229	321	537	835	991	1,268	2,007	1,142	1,971	983	0	0
Total all species	1,059	309	388	658	1,019	1,242	1,478	2,191	1,474	2,491	1,331	0	0
Number of plots	307	38	23	30	64	76	51	16	3	2	4	0	0
Standard error	51	35	48	126	47	66	86	638	358	277	208	0	0
Average basal area	82	37	58	62	81	94	101	125	122	176	98	0	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

Table 93.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Aspen-Birch Unit, Minnesota, 1977[1]

Aspen forest type - Site index class 81-90

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	11	10	20	27	0	19	0	0	0	0	0	0	0
Red pine	3	0	0	0	0	9	0	19	0	0	0	0	0
Jack pine	4	0	0	0	4	7	0	22	39	0	0	0	0
White spruce	16	16	0	6	17	15	35	22	0	0	0	0	0
Black spruce	17	0	0	8	20	14	9	57	155	0	0	0	0
Balsam fir	128	66	105	142	92	166	106	197	312	0	0	0	0
Tamarack	0	0	0	0	0	0	0	0	0	0	0	0	0
Northern white-cedar	2	0	0	0	7	2	0	0	0	0	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	181	92	125	183	139	232	150	317	505	0	0	0	0
Hardwoods:													
Select white oaks	1	0	0	8	0	0	0	0	0	0	0	0	0
Select red oaks	0	0	0	0	0	1	0	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	5	0	0	8	4	2	11	0	0	0	0	0	0
Soft maple	10	0	78	16	1	6	6	0	0	0	0	0	0
Ash	36	0	33	15	35	5	123	14	85	0	0	0	0
Balsam poplar	80	94	13	36	78	65	128	175	166	0	0	0	0
Paper birch	96	54	227	110	73	100	108	18	81	0	0	0	0
Bigtooth aspen	7	0	0	0	2	4	6	0	233	0	0	0	0
Quaking aspen	944	146	198	684	820	1,309	1,350	1,287	660	0	0	0	0
Basswood	15	0	41	51	0	1	29	0	0	0	0	0	0
Elm	11	0	9	7	5	22	21	0	0	0	0	0	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	1,205	294	599	936	1,017	1,516	1,783	1,494	1,224	0	0	0	0
Total all species	1,386	386	724	1,119	1,157	1,748	1,933	1,811	1,730	0	0	0	0
Number of plots	112	7	6	18	29	27	18	5	2	0	0	0	0
Standard error	77	109	83	111	91	141	242	552	980	0	0	0	0
Average basal area	93	41	82	86	85	102	113	106	131	0	0	0	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

Table 94.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Aspen-Birch Unit, Minnesota, 1977[1]

Aspen forest type - Site index class 91-100

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years) 0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	11	0	0	0	0	0	0	192	55	0	0	0	0
Red pine	5	0	0	0	0	12	0	0	0	0	0	0	0
Jack pine	21	0	114	0	38	0	108	0	0	0	0	0	0
White spruce	52	60	0	0	112	51	0	0	0	0	0	0	0
Black spruce	19	0	0	0	0	51	0	0	0	0	0	0	0
Balsam fir	108	0	0	0	83	233	0	84	0	0	0	0	0
Tamarack	0	0	0	0	0	0	0	0	0	0	0	0	0
Northern white-cedar	21	0	0	0	0	21	0	350	0	0	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	236	60	114	0	233	368	108	626	55	0	0	0	0
Hardwoods:													
Select white oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Select red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	1	0	0	0	4	0	0	0	0	0	0	0	0
Soft maple	11	27	0	0	11	11	0	0	0	0	0	0	0
Ash	49	0	0	0	16	19	262	184	156	0	0	0	0
Balsam poplar	185	14	0	375	302	227	0	0	243	0	0	0	0
Paper birch	134	73	182	0	158	144	0	89	330	0	0	0	0
Bigtooth aspen	23	0	0	0	0	38	79	70	0	0	0	0	0
Quaking aspen	1,054	492	638	2,706	1,046	1,137	495	1,228	1,643	0	0	0	0
Basswood	11	0	0	0	49	0	0	0	0	0	0	0	0
Elm	23	0	0	0	10	19	180	0	0	0	0	0	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	1,489	606	820	3,082	1,595	1,596	1,017	1,572	2,372	0	0	0	0
Total all species	1,725	666	934	3,082	1,828	1,963	1,124	2,198	2,427	0	0	0	0
Number of plots	27	4	1	1	6	10	2	1	2	0	0	0	0
Standard error[3]	153	116	R	R	205	174	239	R	1,164	0	0	0	0
Average basal area	105	74	68	142	108	113	65	101	154	0	0	0	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 95.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Aspen-Birch Unit, Minnesota, 1977[1]

Aspen forest type - All site index classes

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	10	4	8	7	7	10	15	13	4	104	27	138	0
Red pine	9	6	0	1	5	12	10	10	39	108	0	58	0
Jack pine	12	4	2	5	15	7	17	48	7	5	0	0	0
White spruce	21	9	9	9	23	16	31	46	62	23	125	46	0
Black spruce	18	13	5	9	14	14	17	55	75	25	18	181	0
Balsam fir	89	26	34	61	79	136	113	111	125	131	204	0	0
Tamarack	1	3	1	0	3	0	0	1	0	0	0	0	0
Northern white-cedar	9	3	8	2	3	9	10	40	3	77	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	170	67	66	94	149	203	213	323	316	472	374	424	0
Hardwoods:													
Select white oaks	2	1	0	2	2	3	2	4	0	0	0	0	0
Select red oaks	1	0	0	0	1	1	1	1	0	7	0	26	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	2	0	0	0	0
Hard maple	3	1	1	2	3	4	3	2	0	24	0	0	0
Soft maple	7	2	5	6	6	12	7	10	11	0	0	24	0
Ash	21	10	10	12	29	16	29	36	39	25	31	0	0
Balsam poplar	48	29	21	28	44	55	84	39	69	70	36	0	0
Paper birch	95	40	55	51	86	131	123	102	190	151	168	47	0
Bigtooth aspen	11	1	2	3	1	15	18	31	56	0	0	0	0
Quaking aspen	551	136	159	323	568	693	810	948	716	885	717	83	0
Basswood	5	4	4	10	6	4	4	1	14	0	0	0	0
Elm	7	3	4	4	2	9	14	9	13	16	37	0	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	1	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	751	226	261	440	747	944	1,094	1,182	1,111	1,177	988	180	0
Total all species	921	293	327	534	897	1,147	1,308	1,505	1,426	1,649	1,362	603	0
Number of plots	1,185	157	125	113	177	256	216	85	35	14	6	1	0
Standard error[3]	23	27	20	55	37	42	53	144	131	255	263	R	0
Average basal area	76	36	52	59	78	89	94	104	104	123	96	71	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 96.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Aspen-Birch Unit, Minnesota, 1977[1]

Paper birch forest type - Site index class 0-50

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)										
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	11	0	0	0	8	4	10	62	0	0	0	0	0
Red pine	4	0	0	0	27	0	8	0	0	0	0	0	0
Jack pine	0	0	0	0	0	0	0	0	0	0	0	0	0
White spruce	24	0	19	0	26	53	22	9	78	0	0	0	0
Black spruce	17	0	0	0	41	37	0	20	0	58	0	0	0
Balsam fir	74	12	70	0	95	95	36	126	134	29	195	0	0
Tamarack	0	0	0	0	0	0	0	0	0	0	0	0	0
Northern white-cedar	9	37	6	0	10	5	7	15	0	0	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	139	49	95	0	208	195	82	232	212	86	195	0	0
Hardwoods:													
Select white oaks	1	0	0	0	0	0	0	8	0	0	0	0	0
Select red oaks	1	0	0	0	0	0	3	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	2	0	0	0	0	0	13	0	0	0	0	0	0
Soft maple	4	0	9	0	0	0	9	0	0	22	0	0	0
Ash	26	0	0	0	0	51	47	53	24	40	0	0	0
Balsam poplar	10	0	4	12	0	9	15	22	25	12	0	0	0
Paper birch	218	35	71	53	221	309	375	324	334	135	0	0	0
Bigtooth aspen	0	0	0	0	0	0	0	0	0	0	0	0	0
Quaking aspen	92	27	41	141	125	190	118	68	74	25	0	0	0
Basswood	7	0	0	0	0	30	15	0	0	0	0	0	0
Elm	3	0	7	0	0	0	7	0	0	17	0	0	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	363	62	131	206	346	590	601	476	457	250	0	0	0
Total all species	502	110	226	206	554	784	684	707	669	337	195	0	0
Number of plots	61	5	11	3	7	9	9	8	4	4	1	0	0
Standard error[3]	47	37	36	42	158	107	105	134	177	123	R	0	0
Average basal area	69	25	52	77	77	94	83	73	88	45	60	0	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 97.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Aspen-Birch Unit, Minnesota, 1977[1]

Paper birch forest type - Site index class 51-60

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)										
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	13	15	20	54	11	8	23	0	11	0	0	0	0
Red pine	5	0	0	0	0	0	10	0	9	18	0	0	0
Jack pine	5	0	0	0	9	0	8	0	23	0	0	0	0
White spruce	37	19	0	0	37	22	51	22	101	0	69	0	0
Black spruce	3	0	0	0	0	5	5	0	0	0	0	0	0
Balsam fir	126	25	23	54	113	109	184	85	109	178	214	0	0
Tamarack	1	0	0	0	0	2	0	0	0	0	0	0	0
Northern white-cedar	13	0	0	0	0	12	6	3	55	68	0	0	0
Other softwoods	1	0	0	0	0	0	3	0	0	0	0	0	0
Total	203	58	43	108	170	159	290	111	309	264	283	0	0
Hardwoods:													
Select white oaks	2	0	0	0	0	0	0	6	0	0	84	0	0
Select red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	10	43	0	0	7	9	5	14	25	0	0	0	0
Soft maple	20	24	20	45	0	40	17	6	9	18	0	0	0
Ash	24	0	0	0	43	21	19	35	21	65	0	0	0
Balsam poplar	21	0	0	0	18	16	21	4	20	88	276	0	0
Paper birch	532	209	129	476	236	608	516	611	696	805	434	0	0
Bigtooth aspen	3	0	0	0	0	4	2	0	12	0	0	0	0
Quaking aspen	164	0	41	213	199	115	189	125	209	465	119	0	0
Basswood	8	0	0	0	0	17	8	8	0	0	0	0	0
Elm	3	0	0	0	0	0	5	3	0	0	60	0	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	786	277	190	735	502	831	782	812	992	1,441	974	0	0
Total all species	989	335	233	843	673	989	1,072	923	1,300	1,706	1,257	0	0
Number of plots	108	4	4	2	8	28	33	14	9	5	1	0	0
Standard error[3]	53	93	87	104	77	83	95	100	247	335	R	0	0
Average basal area	90	71	55	58	70	93	92	91	103	123	112	0	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 98.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Aspen-Birch Unit, Minnesota, 1977[1]

Paper birch forest type - Site index class 61-70

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	11	0	0	0	0	7	15	45	0	0	0	0	0
Red pine	20	0	26	0	0	16	28	22	81	0	0	0	0
Jack pine	1	0	21	0	0	2	0	0	0	0	0	0	0
White spruce	18	0	23	0	6	18	17	14	61	29	0	0	0
Black spruce	9	0	0	0	0	0	12	47	0	0	0	0	0
Balsam fir	124	23	79	0	88	150	127	124	149	133	447	0	0
Tamarack	3	0	0	0	7	3	3	0	0	0	0	0	0
Northern white-cedar	23	0	17	0	22	3	15	0	70	322	85	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	209	23	165	0	122	200	217	253	361	484	532	0	0
Hardwoods:													
Select white oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Select red oaks	7	0	0	0	0	13	10	7	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	4	0	0	0	0	6	8	0	0	27	0	0	0
Hard maple	15	0	0	0	16	15	6	8	51	76	0	0	0
Soft maple	22	12	0	0	4	12	56	16	42	0	0	0	0
Ash	27	0	0	0	14	36	18	0	90	67	0	253	0
Balsam poplar	34	21	0	0	29	41	44	23	9	60	177	0	0
Paper birch	669	197	230	346	671	723	808	626	606	618	287	835	0
Bigtooth aspen	0	0	0	0	0	0	0	0	0	0	0	0	0
Quaking aspen	158	725	99	0	88	140	163	228	103	48	200	318	0
Basswood	15	0	0	0	8	28	6	19	12	0	69	0	0
Elm	6	0	0	0	0	7	8	0	32	0	59	0	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	957	955	329	346	830	1,020	1,128	926	944	896	791	1,406	0
Total all species	1,166	978	494	346	952	1,220	1,345	1,179	1,305	1,380	1,323	1,406	0
Number of plots	107	3	4	2	16	31	25	14	7	3	1	1	0
Standard error[3]	54	566	186	81	157	90	86	154	218	335	R	R	0
Average basal area	92	89	75	53	81	92	100	91	96	100	105	116	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 99.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Aspen-Birch Unit, Minnesota, 1977[1]

Paper birch forest type - Site index class 71-80

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	3	0	0	0	0	6	0	0	0	0	0	0	0
Red pine	96	0	0	0	0	40	0	0	1,020	0	0	0	0
Jack pine	2	0	0	0	0	4	0	0	0	0	0	0	0
White spruce	33	0	82	0	0	33	0	0	88	0	89	0	0
Black spruce	4	0	59	0	0	0	0	0	0	0	0	0	0
Balsam fir	120	0	143	0	37	97	40	379	279	0	392	0	0
Tamarack	0	0	0	0	0	0	0	0	0	0	0	0	0
Northern white-cedar	20	0	0	0	0	0	0	251	141	0	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	279	0	284	0	37	180	40	630	1,528	0	481	0	0
Hardwoods:													
Select white oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Select red oaks	2	0	0	0	14	0	0	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	5	0	0	0	0	0	0	0	66	0	0	0	0
Hard maple	14	0	0	0	15	9	63	0	0	0	0	0	0
Soft maple	12	0	0	0	13	9	48	0	0	0	0	0	0
Ash	34	0	0	0	67	41	0	81	0	0	0	0	0
Balsam poplar	77	0	0	0	100	86	67	229	21	0	0	0	0
Paper birch	692	0	88	0	430	697	791	612	1,081	0	1,880	0	0
Bigtooth aspen	8	0	0	0	0	9	26	0	0	0	0	0	0
Quaking aspen	201	0	112	0	190	207	254	427	138	0	93	0	0
Basswood	8	0	0	0	16	0	0	0	72	0	0	0	0
Elm	0	0	0	0	0	0	0	0	0	0	0	0	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	1,053	0	199	0	845	1,059	1,248	1,348	1,378	0	1,973	0	0
Total all species	1,331	0	483	0	882	1,239	1,288	1,978	2,906	0	2,454	0	0
Number of plots	27	0	2	0	4	14	3	1	2	0	1	0	0
Standard error[3]	147	0	289	0	252	113	282	R	1,111	0	R	0	0
Average basal area	94	0	45	0	70	93	101	142	150	0	124	0	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 100.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Aspen-Birch Unit, Minnesota, 1977[1]

Paper birch forest type - All site index classes

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	12	5	11	15	4	7	18	31	4	0	0	0	0
Red pine	18	0	5	0	5	13	16	8	122	7	0	0	0
Jack pine	2	0	4	0	2	2	4	0	9	0	0	0	0
White spruce	27	6	21	0	16	25	33	16	83	7	39	0	0
Black spruce	8	0	5	0	8	6	6	22	0	19	0	0	0
Balsam fir	115	19	69	15	89	123	138	117	142	117	312	0	0
Tamarack	1	0	0	0	3	2	1	0	0	0	0	0	0
Northern white-cedar	16	15	6	0	12	6	9	11	58	109	21	0	0
Other softwoods	0	0	0	0	0	0	1	0	0	0	0	0	0
Total	199	46	120	31	141	183	227	204	418	260	373	0	0
Hardwoods:													
Select white oaks	1	0	0	0	0	0	0	4	0	0	21	0	0
Select red oaks	3	0	0	0	2	5	4	3	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	2	0	0	0	0	2	3	0	6	7	0	0	0
Hard maple	10	14	0	0	11	10	9	8	27	19	0	0	0
Soft maple	17	11	8	13	3	20	31	8	17	15	0	0	0
Ash	26	0	0	0	24	34	22	27	42	57	0	253	0
Balsam poplar	28	5	2	5	29	37	31	21	17	56	113	0	0
Paper birch	530	134	124	258	454	631	614	555	636	535	650	835	0
Bigtooth aspen	2	0	0	0	0	3	2	0	5	0	0	0	0
Quaking aspen	152	192	64	122	132	152	173	160	144	214	103	318	0
Basswood	10	0	0	0	5	20	8	10	10	0	17	0	0
Elm	4	0	3	0	0	3	6	1	10	6	30	0	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	785	357	202	397	660	915	903	797	915	908	935	1,406	0
Total all species	984	402	322	428	800	1,099	1,129	1,002	1,333	1,168	1,307	1,406	0
Number of plots	305	12	22	7	35	83	70	37	22	12	4	1	0
Standard error[3]	34	163	53	114	87	51	62	84	186	238	462	R	0
Average basal area	87	56	56	64	76	93	94	89	102	91	100	116	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 101.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Aspen-Birch Unit, Minnesota, 1977[1]

Balsam poplar forest type - Site index class 0-50

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	0	0	0	0	0	0	0	0	0	0	0	0	0
Red pine	0	0	0	0	0	0	0	0	0	0	0	0	0
Jack pine	0	0	0	0	0	0	0	0	0	0	0	0	0
White spruce	16	0	0	0	0	31	39	0	0	0	0	0	0
Black spruce	5	0	0	0	0	0	0	0	44	0	0	0	0
Balsam fir	98	0	18	0	0	37	129	0	486	0	0	0	0
Tamarack	0	0	0	0	0	0	0	0	0	0	0	0	0
Northern white-cedar	5	0	0	0	0	0	0	0	39	0	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	125	0	18	0	0	68	168	0	570	0	0	0	0
Hardwoods:													
Select white oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Select red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Soft maple	2	0	0	0	0	0	7	0	0	0	0	0	0
Ash	30	0	0	0	0	86	0	73	48	0	0	0	0
Balsam poplar	221	34	42	0	0	309	461	173	175	0	0	0	0
Paper birch	52	0	0	0	0	28	57	50	247	0	0	0	0
Bigtooth aspen	5	0	0	0	0	0	0	0	44	0	0	0	0
Quaking aspen	60	61	0	40	0	97	51	138	47	0	0	0	0
Basswood	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	10	0	0	0	0	10	0	0	62	0	0	0	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	380	95	42	40	0	531	575	433	622	0	0	0	0
Total all species	504	95	60	40	0	598	743	433	1,192	0	0	0	0
Number of plots	17	2	2	2	0	4	4	1	2	0	0	0	0
Standard error[3]	100	95	60	40	0	134	94	R	98	0	0	0	0
Average basal area	55	8	10	12	0	70	71	68	118	0	0	0	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 102.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Aspen-Birch Unit, Minnesota, 1977[1]

Balsam poplar forest type - Site index class 51-60

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	2	0	0	0	0	0	17	0	0	0	0	0	0
Red pine	0	0	0	0	0	0	0	0	0	0	0	0	0
Jack pine	0	0	0	0	0	0	0	0	0	0	0	0	0
White spruce	6	19	0	0	0	6	0	0	35	0	0	0	0
Black spruce	11	29	0	0	0	21	9	0	0	0	0	0	0
Balsam fir	92	0	0	0	36	169	72	191	24	56	0	0	0
Tamarack	0	0	0	0	0	0	0	0	0	0	0	0	0
Northern white-cedar	17	0	37	0	8	38	0	0	0	0	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	127	49	37	0	44	234	98	191	60	56	0	0	0
Hardwoods:													
Select white oaks	2	0	0	0	0	5	0	0	0	0	0	0	0
Select red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	5	0	0	0	0	0	0	0	0	159	0	0	0
Hard maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Soft maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	38	0	0	0	8	63	28	17	0	369	0	0	0
Balsam poplar	386	144	88	0	342	536	496	189	471	493	0	0	0
Paper birch	68	14	0	0	62	100	44	65	37	315	0	0	0
Bigtooth aspen	2	0	0	0	0	8	0	0	0	0	0	0	0
Quaking aspen	71	49	15	0	65	49	46	212	180	62	0	0	0
Basswood	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	14	0	13	0	14	33	0	0	0	0	0	0	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	586	207	116	0	491	793	614	483	688	1,397	0	0	0
Total all species	713	255	154	0	535	1,026	712	673	748	1,453	0	0	0
Number of plots	34	3	3	0	6	11	5	3	2	1	0	0	0
Standard error[3]	92	97	91	0	88	205	77	414	120	R	0	0	0
Average basal area	71	27	18	0	71	96	74	63	55	124	0	0	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 103.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Aspen-Birch Unit, Minnesota, 1977[1]

Balsam poplar forest type - Site index class 61-70

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	0	0	0	0	0	0	0	0	0	0	0	0	0
Red pine	1	0	0	16	0	0	0	0	0	0	0	0	0
Jack pine	1	12	0	0	0	0	0	0	0	0	0	0	0
White spruce	16	47	0	0	0	0	35	17	22	45	0	0	0
Black spruce	6	23	0	0	11	0	14	0	0	0	0	0	0
Balsam fir	110	72	11	33	219	122	93	220	235	107	0	0	0
Tamarack	4	0	0	0	0	0	20	0	0	0	0	0	0
Northern white-cedar	39	0	4	0	91	15	88	27	150	0	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	178	153	15	49	321	138	249	263	407	152	0	0	0
Hardwoods:													
Select white oaks	1	0	0	0	8	0	0	0	0	0	0	0	0
Select red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	7	0	0	12	0	27	0	11	0	0	0	0	0
Soft maple	1	0	0	0	11	0	0	0	0	0	0	0	0
Ash	66	30	0	15	152	29	12	95	327	258	166	0	0
Balsam poplar	452	106	171	125	608	428	581	798	710	654	869	0	0
Paper birch	54	27	22	0	65	155	8	36	89	73	0	0	0
Bigtooth aspen	0	0	0	0	0	0	0	0	0	0	0	0	0
Quaking aspen	77	77	55	97	101	86	68	107	0	140	0	0	0
Basswood	6	11	0	0	0	0	0	0	23	97	0	0	0
Elm	21	12	0	10	37	0	11	12	54	208	64	0	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	685	264	248	260	983	724	680	1,058	1,203	1,431	1,098	0	0
Total all species	862	417	263	309	1,303	862	929	1,321	1,609	1,582	1,098	0	0
Number of plots	51	5	7	4	4	10	10	5	3	2	1	0	0
Standard error[3]	83	65	100	52	129	203	141	152	479	48	R	0	0
Average basal area	73	32	41	51	110	69	69	112	112	111	120	0	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 104.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Aspen-Birch Unit, Minnesota, 1977[1]

Balsam poplar forest type - Site index class 71-80

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	0	0	0	0	0	0	0	0	0	0	0	0	0
Red pine	0	0	0	0	0	0	0	0	0	0	0	0	0
Jack pine	0	0	0	0	0	0	0	0	0	0	0	0	0
White spruce	26	0	114	0	15	60	0	0	0	0	0	0	0
Black spruce	4	19	0	0	4	0	0	0	0	0	0	0	0
Balsam fir	135	22	124	0	22	265	252	0	0	0	0	0	0
Tamarack	0	0	0	0	0	0	0	0	0	0	0	0	0
Northern white-cedar	5	0	0	122	0	0	0	0	0	0	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	169	41	238	122	42	325	252	0	0	0	0	0	0
Hardwoods:													
Select white oaks	2	0	0	0	7	0	0	0	0	0	0	0	0
Select red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Soft maple	4	0	0	0	12	0	0	0	0	0	0	0	0
Ash	27	54	0	134	0	13	63	0	0	0	0	0	0
Balsam poplar	564	134	0	0	425	799	968	0	0	0	0	0	0
Paper birch	70	27	0	0	94	67	85	0	0	0	0	0	0
Bigtooth aspen	0	0	0	0	0	0	0	0	0	0	0	0	0
Quaking aspen	135	26	111	0	103	244	139	0	0	0	0	0	0
Basswood	3	26	0	0	0	0	0	0	0	0	0	0	0
Elm	53	0	0	0	32	101	75	0	0	0	0	0	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	858	267	111	134	672	1,224	1,331	0	0	0	0	0	0
Total all species	1,027	309	348	257	714	1,548	1,583	0	0	0	0	0	0
Number of plots	26	3	1	1	9	7	5	0	0	0	0	0	0
Standard error[3]	128	84	R	R	114	204	217	0	0	0	0	0	0
Average basal area	78	33	30	34	64	107	110	0	0	0	0	0	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 105.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Aspen-Birch Unit, Minnesota, 1977[1]

Balsam poplar forest type - Site index class 81-90

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	0	0	0	0	0	0	0	0	0	0	0	0	0
Red pine	0	0	0	0	0	0	0	0	0	0	0	0	0
Jack pine	0	0	0	0	0	0	0	0	0	0	0	0	0
White spruce	17	16	0	0	33	18	0	0	0	0	0	0	0
Black spruce	24	0	0	0	0	73	0	0	0	0	0	0	0
Balsam fir	189	0	0	0	111	377	0	80	215	0	0	0	0
Tamarack	0	0	0	0	0	0	0	0	0	0	0	0	0
Northern white-cedar	0	0	0	0	0	0	0	0	0	0	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	231	16	0	0	144	469	0	80	215	0	0	0	0
Hardwoods:													
Select white oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Select red oaks	20	0	0	0	0	0	0	0	151	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	8	0	0	0	0	0	0	0	63	0	0	0	0
Soft maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	47	0	0	0	131	22	0	71	0	0	0	0	0
Balsam poplar	818	118	0	0	897	1,181	214	1,185	569	0	0	0	0
Paper birch	106	0	0	0	105	142	47	76	170	0	0	0	0
Bigtooth aspen	0	0	0	0	0	0	0	0	0	0	0	0	0
Quaking aspen	318	0	0	0	256	518	244	484	213	0	0	0	0
Basswood	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	27	0	0	0	0	44	0	0	96	0	0	0	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	1,345	118	0	0	1,389	1,906	505	1,816	1,263	0	0	0	0
Total all species	1,576	134	0	0	1,534	2,375	505	1,896	1,478	0	0	0	0
Number of plots	15	2	0	0	4	5	1	1	2	0	0	0	0
Standard error[3]	220	134	0	0	246	192	R	R	97	0	0	0	0
Average basal area	103	23	0	0	110	133	41	120	115	0	0	0	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 106.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Aspen-Birch Unit, Minnesota, 1977[1]

Balsam poplar forest type - All site index classes

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)										
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:												
White pine	1	0	0	0	0	0	3	0	0	0	0	0	0
Red pine	0	0	0	8	0	0	0	0	0	0	0	0	0
Jack pine	0	4	0	0	0	0	0	0	0	0	0	0	0
White spruce	16	22	9	0	11	19	20	17	15	30	0	0	0
Black spruce	8	17	0	0	3	16	8	0	10	0	0	0	0
Balsam fir	115	28	18	17	70	188	123	176	240	90	0	0	0
Tamarack	1	0	0	0	0	0	8	0	0	0	0	0	0
Northern white-cedar	19	0	11	15	16	15	35	12	59	0	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	161	71	38	40	100	239	197	205	323	120	0	0	0
Hardwoods:													
Select white oaks	1	0	0	0	4	2	0	0	0	0	0	0	0
Select red oaks	2	0	0	0	0	0	0	0	34	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	1	0	0	0	0	0	0	0	0	53	0	0	0
Hard maple	3	0	0	6	0	7	0	5	14	0	0	0	0
Soft maple	1	0	0	0	6	0	1	0	0	0	0	0	0
Ash	50	21	0	35	54	41	23	110	120	295	166	0	0
Balsam poplar	478	111	119	154	531	619	607	657	507	601	869	0	0
Paper birch	64	17	12	13	76	106	40	45	130	154	0	0	0
Bigtooth aspen	1	0	0	0	0	2	0	0	10	0	0	0	0
Quaking aspen	126	49	42	120	155	164	82	279	98	114	0	0	0
Basswood	3	9	0	0	0	0	0	0	8	64	0	0	0
Elm	26	4	3	17	29	36	20	5	53	139	64	0	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	757	211	175	344	855	978	773	1,102	973	1,419	1,098	0	0
Total all species	918	282	213	384	955	1,216	970	1,307	1,296	1,539	1,098	0	0
Number of plots	147	15	13	8	25	37	25	11	9	3	1	0	0
Standard error[3]	57	46	61	167	102	128	97	274	184	51	R	0	0
Average basal area	75	27	30	45	81	93	77	98	101	115	120	0	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 107.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Northern Pine Unit, Minnesota, 1977[1]

Jack pine forest type - Site index class 0-50

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years) 0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	3	0	0	0	0	10	2	0	0	0	0	0	0
Red pine	47	52	125	0	78	50	54	0	0	0	0	0	0
Jack pine	462	174	0	59	470	452	701	627	515	0	0	0	0
White spruce	0	0	0	0	0	0	0	0	0	0	0	0	0
Black spruce	0	0	0	0	0	0	0	0	0	0	0	0	0
Balsam fir	0	0	0	0	0	0	0	0	0	0	0	0	0
Tamarack	0	0	0	0	0	0	0	0	0	0	0	0	0
Northern white-cedar	0	0	0	0	0	0	0	0	0	0	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	512	226	125	59	548	512	758	627	515	0	0	0	0
Hardwoods:													
Select white oaks	3	0	0	0	0	10	0	0	0	0	0	0	0
Select red oaks	20	0	0	0	0	76	0	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Soft maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	0	0	0	0	0	0	0	0	0	0	0	0	0
Balsam poplar	1	0	0	0	0	4	0	0	0	0	0	0	0
Paper birch	21	0	0	0	0	66	14	0	0	0	0	0	0
Bigtooth aspen	1	0	0	0	0	4	0	0	0	0	0	0	0
Quaking aspen	6	0	12	0	9	15	0	0	0	0	0	0	0
Basswood	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	0	0	0	0	0	0	0	0	0	0	0	0	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	52	0	12	0	9	176	14	0	0	0	0	0	0
Total all species	564	226	137	59	557	688	772	627	515	0	0	0	0
Number of plots	34	2	3	2	3	9	8	5	2	0	0	0	0
Standard error	77	74	106	59	261	127	172	275	50	0	0	0	0
Average basal area	65	30	54	53	77	69	80	58	54	0	0	0	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

Table 108.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Northern Pine Unit, Minnesota, 1977[1]

Jack pine forest type - Site index class 51-60

(In cubic feet per acre)

Species	Average[2]	0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
		Stand-age class (years)											
Softwoods:													
White pine	3	0	0	0	0	4	0	8	18	0	0	0	0
Red pine	52	92	12	0	39	45	60	120	136	0	0	0	0
Jack pine	812	444	153	373	711	830	1,094	978	1,435	0	806	0	0
White spruce	6	0	0	0	0	15	9	0	0	0	0	0	0
Black spruce	2	0	0	6	0	3	2	0	0	0	0	0	0
Balsam fir	2	0	0	0	0	0	6	0	0	0	0	0	0
Tamarack	1	0	0	0	0	4	0	0	0	0	0	0	0
Northern white-cedar	0	0	0	0	0	0	0	0	0	0	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	878	536	165	379	750	900	1,172	1,106	1,588	0	806	0	0
Hardwoods:													
Select white oaks	3	0	0	0	3	0	11	4	0	0	0	0	0
Select red oaks	5	0	0	0	4	4	3	7	0	0	157	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Soft maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	0	0	0	0	0	0	0	0	0	0	0	0	0
Balsam poplar	1	0	0	0	0	1	4	0	0	0	0	0	0
Paper birch	10	0	7	0	6	1	15	19	20	0	164	0	0
Bigtooth aspen	2	0	0	0	0	0	0	23	0	0	0	0	0
Quaking aspen	41	0	0	21	65	61	28	76	0	0	0	0	0
Basswood	1	0	0	0	0	0	0	6	0	0	0	0	0
Elm	0	0	0	0	0	0	0	0	0	0	0	0	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	63	0	7	21	77	68	60	134	20	0	321	0	0
Total all species	941	536	172	400	827	968	1,232	1,240	1,608	0	1,127	0	0
Number of plots	86	3	5	10	10	24	22	8	3	0	1	0	0
Standard error[3]	57	145	60	72	60	92	97	201	372	0	R	0	0
Average basal area	79	53	30	62	91	79	90	89	99	0	71	0	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 109.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Northern Pine Unit, Minnesota, 1977[1]

Jack pine forest type - Site index class 61-70

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	4	0	0	6	0	11	0	0	0	0	0	0	0
Red pine	85	0	45	84	108	67	107	82	0	0	0	0	0
Jack pine	1,046	409	70	596	908	1,245	1,135	1,955	0	0	0	0	0
White spruce	3	0	0	0	3	5	4	0	0	0	0	0	0
Black spruce	18	0	0	10	9	30	19	0	0	0	0	0	0
Balsam fir	8	0	65	8	9	3	10	0	0	0	0	0	0
Tamarack	0	0	0	0	0	0	0	0	0	0	0	0	0
Northern white-cedar	0	0	0	0	0	0	0	0	0	0	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	1,164	409	180	703	1,038	1,361	1,275	2,037	0	0	0	0	0
Hardwoods:													
Select white oaks	3	0	0	0	0	6	4	0	0	0	0	0	0
Select red oaks	8	60	0	30	0	0	12	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Soft maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	1	0	0	0	0	2	0	0	0	0	0	0	0
Balsam poplar	2	0	0	0	0	0	10	0	0	0	0	0	0
Paper birch	30	18	119	9	22	27	41	53	0	0	0	0	0
Bigtooth aspen	14	0	0	0	14	10	34	0	0	0	0	0	0
Quaking aspen	36	25	0	26	27	37	61	0	0	0	0	0	0
Basswood	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	1	0	0	2	0	1	4	0	0	0	0	0	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	2	0	0	0	0	0	10	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	97	104	119	67	64	83	175	53	0	0	0	0	0
Total all species	1,261	513	298	770	1,102	1,444	1,450	2,089	0	0	0	0	0
Number of plots	73	2	2	8	17	25	16	3	0	0	0	0	0
Standard error	68	36	120	156	93	105	148	189	0	0	0	0	0
Average basal area	89	57	45	89	84	95	89	125	0	0	0	0	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

Table 110.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Northern Pine Unit, Minnesota, 1977[1]

Jack pine forest type - Site index class 71-80

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years) 0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	3	0	0	0	8	0	0	0	0	0	0	0	0
Red pine	144	0	0	101	75	433	42	114	0	0	0	0	0
Jack pine	928	561	114	832	738	1,180	943	1,970	0	0	0	0	0
White spruce	3	0	0	0	6	0	0	0	0	0	0	0	0
Black spruce	41	0	0	0	103	0	0	0	0	0	0	0	0
Balsam fir	18	0	0	17	4	0	0	140	0	0	0	0	0
Tamarack	0	0	0	0	0	0	0	0	0	0	0	0	0
Northern white-cedar	0	0	0	0	0	0	0	0	0	0	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	1,138	561	114	950	935	1,613	985	2,224	0	0	0	0	0
Hardwoods:													
Select white oaks	3	0	0	0	9	0	0	0	0	0	0	0	0
Select red oaks	11	0	0	31	17	0	0	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Soft maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	0	0	0	0	0	0	0	0	0	0	0	0	0
Balsam poplar	5	0	0	0	0	0	0	46	0	0	0	0	0
Paper birch	34	0	0	41	56	9	0	39	0	0	0	0	0
Bigtooth aspen	22	0	0	0	54	0	0	0	0	0	0	0	0
Quaking aspen	103	0	0	0	73	254	164	116	0	0	0	0	0
Basswood	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	0	0	0	0	0	0	0	0	0	0	0	0	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	177	0	0	72	209	263	164	201	0	0	0	0	0
Total all species	1,314	561	114	1,022	1,143	1,877	1,150	2,424	0	0	0	0	0
Number of plots	30	1	2	4	12	6	2	3	0	0	0	0	0
Standard error[3]	149	R	114	239	190	109	148	789	0	0	0	0	0
Average basal area	93	75	68	86	85	111	77	132	0	0	0	0	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 111.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Northern Pine Unit, Minnesota, 1977[1]

Jack pine forest type - All site index classes

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	4	0	0	2	4	7	0	3	11	0	0	0	0
Red pine	75	48	44	43	80	91	74	83	81	0	0	0	0
Jack pine	849	382	94	505	791	972	1,036	1,152	1,067	0	806	0	0
White spruce	4	0	0	0	3	8	5	0	0	0	0	0	0
Black spruce	12	0	0	6	31	13	7	0	0	0	0	0	0
Balsam fir	6	0	11	5	4	1	6	23	0	0	0	0	0
Tamarack	0	0	0	0	0	1	0	0	0	0	0	0	0
Northern white-cedar	0	0	0	0	0	0	0	0	0	0	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	949	430	149	561	914	1,093	1,129	1,260	1,159	0	806	0	0
Hardwoods:													
Select white oaks	3	0	0	0	3	4	6	1	0	0	0	0	0
Select red oaks	9	15	0	15	5	12	5	3	0	0	157	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Soft maple	0	0	0	0	1	0	0	0	0	0	0	0	0
Ash	0	0	0	0	0	1	0	0	0	0	0	0	0
Balsam poplar	2	0	0	0	0	1	5	7	0	0	0	0	0
Paper birch	23	5	23	10	34	21	23	22	12	0	164	0	0
Bigtooth aspen	9	0	0	0	21	5	11	9	0	0	0	0	0
Quaking aspen	47	6	3	17	71	63	40	48	0	0	0	0	0
Basswood	0	0	0	0	0	0	0	2	0	0	0	0	0
Elm	0	0	0	1	0	0	1	0	0	0	0	0	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	1	0	0	0	0	0	3	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	93	26	26	41	135	107	95	92	12	0	321	0	0
Total all species	1,042	456	174	603	1,049	1,200	1,224	1,352	1,171	0	1,127	0	0
Number of plots	228	8	12	25	45	64	48	20	5	0	1	0	0
Standard error[3]	42	71	42	86	76	72	78	208	337	0	R	0	0
Average basal area	82	51	45	75	86	87	88	92	81	0	71	0	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 112.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Northern Pine Unit, Minnesota, 1977[1]

Red pine forest type - Site index class 51-60

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years) 0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	92	0	0	0	0	81	0	27	117	532	89	0	0
Red pine	1,132	0	0	0	417	789	987	1,194	1,811	567	1,241	0	0
Jack pine	88	0	0	0	0	177	705	148	0	0	0	0	0
White spruce	6	0	0	0	0	0	0	0	16	0	0	0	0
Black spruce	4	0	0	0	0	0	0	0	11	0	0	0	0
Balsam fir	67	0	0	0	0	211	0	0	0	0	723	0	0
Tamarack	10	0	0	0	0	0	0	0	29	0	0	0	0
Northern white-cedar	0	0	0	0	0	0	0	0	0	0	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	1,399	0	0	0	417	1,257	1,692	1,368	1,984	1,099	2,054	0	0
Hardwoods:													
Select white oaks	10	0	0	0	39	0	0	11	0	100	0	0	0
Select red oaks	10	0	0	0	47	0	0	0	11	60	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Soft maple	2	0	0	0	41	0	0	0	0	0	0	0	0
Ash	0	0	0	0	0	0	0	0	0	0	0	0	0
Balsam poplar	2	0	0	0	0	0	0	0	6	0	0	0	0
Paper birch	79	0	0	0	92	0	0	0	195	0	72	0	0
Bigtooth aspen	28	0	0	0	0	0	0	0	80	0	0	0	0
Quaking aspen	99	0	0	0	154	124	0	105	152	0	46	0	0
Basswood	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	0	0	0	0	0	0	0	0	0	0	0	0	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	231	0	0	0	373	124	0	117	445	160	119	0	0
Total all species	1,630	0	0	0	789	1,382	1,692	1,485	2,429	1,259	2,172	0	0
Number of plots	17	2	0	0	1	2	1	3	6	1	1	0	0
Standard error[3]	267	0	0	0	R	66	R	561	485	R	R	0	0
Average basal area	107	12	0	0	71	122	116	89	134	94	202	0	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 113.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Northern Pine Unit, Minnesota, 1977[1]

Red pine forest type - Site index class 61-70

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)										
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	117	0	0	0	41	0	245	33	750	0	211	0	0
Red pine	1,131	196	89	1,113	1,030	856	984	1,703	2,854	0	1,390	0	0
Jack pine	91	165	0	0	0	386	277	0	0	0	0	0	0
White spruce	22	0	0	245	0	0	35	0	0	0	0	0	0
Black spruce	0	0	0	0	0	0	0	0	0	0	0	0	0
Balsam fir	28	0	0	0	0	233	0	14	0	0	122	0	0
Tamarack	0	0	0	0	0	0	0	0	0	0	0	0	0
Northern white-cedar	0	0	0	0	0	0	0	0	0	0	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	1,389	361	89	1,358	1,072	1,475	1,540	1,751	3,603	0	1,723	0	0
Hardwoods:													
Select white oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Select red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Soft maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	7	0	0	0	0	0	49	0	0	0	0	0	0
Balsam poplar	28	0	0	0	0	280	54	0	0	0	0	0	0
Paper birch	28	0	0	0	95	0	62	0	0	0	83	0	0
Bigtooth aspen	14	0	0	0	30	0	0	0	0	0	131	0	0
Quaking aspen	104	0	0	0	86	53	493	14	205	0	0	0	0
Basswood	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	2	0	0	0	0	0	16	0	0	0	0	0	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	6	0	0	0	0	0	0	0	85	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	190	0	0	0	212	333	674	14	291	0	214	0	0
Total all species	1,578	361	89	1,358	1,284	1,808	2,214	1,765	3,894	0	1,937	0	0
Number of plots	14	2	1	1	2	1	2	3	1	0	1	0	0
Standard error[3]	289	361	R	R	246	R	1	708	R	0	R	0	0
Average basal area	92	29	52	90	85	109	131	94	154	0	109	0	0

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[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 114.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Northern Pine Unit, Minnesota, 1977[1]

Red pine forest type - All site index classes

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years) 0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	113	0	0	0	21	73	122	33	292	532	145	231	0
Red pine	1,035	78	45	967	997	892	895	1,161	1,925	567	894	696	0
Jack pine	116	84	0	61	285	292	343	71	0	0	0	0	0
White spruce	12	0	0	82	0	24	17	0	9	0	0	0	0
Black spruce	5	0	0	58	0	0	0	0	7	0	0	0	0
Balsam fir	41	0	0	0	0	150	0	5	12	0	211	0	0
Tamarack	3	0	0	0	0	0	0	0	17	0	0	0	0
Northern white-cedar	0	0	0	0	0	0	0	0	0	0	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	1,324	162	45	1,167	1,302	1,430	1,377	1,270	2,263	1,099	1,251	927	0
Hardwoods:													
Select white oaks	3	0	0	0	10	0	0	4	0	100	0	0	0
Select red oaks	10	0	78	0	37	0	8	0	12	60	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Soft maple	1	0	0	0	10	0	0	0	0	0	0	0	0
Ash	2	0	0	0	0	0	24	0	0	0	0	0	0
Balsam poplar	10	0	0	0	0	47	27	0	4	0	0	0	0
Paper birch	66	0	39	0	158	24	31	0	200	0	74	0	0
Bigtooth aspen	13	0	0	0	15	0	0	0	48	0	33	0	0
Quaking aspen	87	0	0	0	142	54	247	48	171	0	12	227	0
Basswood	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	1	0	0	0	0	0	8	0	0	0	0	0	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	2	0	0	0	0	0	0	0	9	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	195	0	118	0	373	125	346	52	443	160	119	227	0
Total all species	1,519	162	162	1,167	1,675	1,556	1,723	1,322	2,707	1,259	1,369	1,154	0
Number of plots	50	5	2	3	4	7	4	9	10	1	4	1	0
Standard error[3]	149	141	73	287	577	206	341	306	320	R	399	R	0
Average basal area	98	18	62	102	96	113	117	80	137	94	107	128	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 115.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Northern Pine Unit, Minnesota, 1977[1]

White pine forest type - All site index classes

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	766	0	0	0	517	605	651	533	586	1,329	1,228	1,228	0
Red pine	344	0	0	0	41	377	360	582	187	0	0	1,350	0
Jack pine	71	0	0	0	60	176	0	38	110	0	0	0	0
White spruce	27	0	0	0	249	0	0	0	78	0	0	0	0
Black spruce	12	0	0	0	0	0	88	0	0	0	0	0	0
Balsam fir	65	0	0	0	39	22	106	0	0	71	281	0	0
Tamarack	0	0	0	0	0	0	0	0	0	0	0	0	0
Northern white-cedar	0	0	0	0	0	0	0	0	0	0	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	1,284	0	0	0	905	1,180	1,205	1,153	961	1,400	1,509	2,578	0
Hardwoods:													
Select white oaks	15	0	0	0	0	10	0	93	0	0	0	0	0
Select red oaks	5	0	0	0	0	0	0	0	0	80	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	12	0	0	0	0	0	0	0	0	0	89	0	0
Soft maple	2	0	0	0	0	0	16	0	0	0	0	0	0
Ash	0	0	0	0	0	0	0	0	0	0	0	0	0
Balsam poplar	2	0	0	0	0	8	0	0	0	0	0	0	0
Paper birch	128	0	0	0	158	143	138	55	54	161	244	55	0
Bigtooth aspen	0	0	0	0	0	0	0	0	0	0	0	0	0
Quaking aspen	68	0	0	0	0	9	326	43	83	79	0	0	0
Basswood	24	0	0	0	0	0	0	0	0	224	66	0	0
Elm	0	0	0	0	0	0	0	0	0	0	0	0	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	257	0	0	0	158	169	479	190	137	544	400	55	0
Total all species	1,541	0	0	0	1,063	1,350	1,684	1,343	1,098	1,945	1,909	2,632	0
Number of plots	15	0	0	0	1	4	2	2	2	1	2	1	0
Standard error[3]	165	0	0	0	R	205	627	411	79	R	880	R	0
Average basal area	103	0	0	0	82	96	113	92	99	98	109	153	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 116.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Northern Pine Unit, Minnesota, 1977[1]

Black spruce forest type - Site index class 0-50

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	0	0	0	0	0	2	0	0	0	0	0	0	0
Red pine	0	0	0	0	0	0	0	0	0	0	0	0	0
Jack pine	2	0	0	0	0	3	0	0	34	0	0	0	0
White spruce	1	0	0	0	1	0	4	7	0	0	0	0	0
Black spruce	234	75	88	78	90	262	414	373	338	542	481	225	575
Balsam fir	14	4	0	2	6	44	50	0	0	17	0	36	0
Tamarack	55	2	36	48	41	102	57	116	75	51	57	9	0
Northern white-cedar	14	3	0	3	2	12	44	0	57	31	0	47	33
Other softwoods	1	0	0	0	0	0	0	9	0	0	0	0	0
Total	321	84	124	131	141	426	569	504	504	641	538	317	608
Hardwoods:													
Select white oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Select red oaks	0	0	0	1	1	0	0	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Soft maple	1	0	0	0	0	0	6	0	0	0	0	0	0
Ash	2	0	0	0	0	13	0	0	0	0	9	7	0
Balsam poplar	1	0	0	0	0	2	4	0	0	0	0	0	0
Paper birch	4	0	0	1	4	5	2	4	0	21	0	0	0
Bigtooth aspen	1	0	0	4	0	0	0	0	0	0	0	0	0
Quaking aspen	7	4	0	6	9	23	21	0	0	0	0	0	0
Basswood	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	0	0	0	0	0	0	0	0	0	0	0	17	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	16	4	0	11	14	43	33	4	0	21	9	24	0
Total all species	337	88	124	143	155	468	602	508	504	662	547	340	608
Number of plots	161	12	11	36	24	15	18	13	8	16	3	3	2
Standard error	31	48	42	24	33	128	139	105	155	114	135	134	339
Average basal area	64	22	22	47	55	80	102	75	66	93	115	60	111

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

Table 117.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Northern Pine Unit, Minnesota, 1977[1]

Black spruce forest type - All site index classes

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	0	0	0	0	0	2	0	0	0	0	0	0	0
Red pine	0	0	0	0	0	0	0	0	0	0	0	0	0
Jack pine	2	0	0	0	0	3	0	0	34	0	0	0	0
White spruce	1	0	0	0	1	0	5	6	0	0	0	0	0
Black spruce	233	71	87	80	96	262	408	413	338	542	481	225	575
Balsam fir	14	9	0	2	9	44	47	5	0	17	0	36	0
Tamarack	54	2	50	44	42	102	54	113	75	51	57	9	0
Northern white-cedar	15	2	0	7	2	12	42	0	57	31	0	47	33
Other softwoods	1	0	0	0	0	0	0	8	0	0	0	0	0
Total	319	84	137	134	151	426	556	545	504	641	538	317	608
Hardwoods:													
Select white oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Select red oaks	0	0	0	1	1	0	0	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Soft maple	1	0	0	0	0	0	6	0	0	0	0	0	0
Ash	1	0	0	0	0	13	0	0	0	0	9	7	0
Balsam poplar	1	0	0	0	0	2	3	0	0	0	0	0	0
Paper birch	4	0	0	2	4	5	2	4	0	21	0	0	0
Bigtooth aspen	1	0	0	3	0	0	0	0	0	0	0	0	0
Quaking aspen	9	3	0	6	23	23	20	0	0	0	0	0	0
Basswood	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	0	0	0	0	0	0	0	0	0	0	0	17	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	17	3	0	12	28	43	31	4	0	21	9	24	0
Total all species	337	87	137	146	179	468	587	549	504	662	547	340	608
Number of plots	171	14	13	39	25	15	19	14	8	16	3	3	2
Standard error	30	42	41	22	40	128	132	105	155	114	135	134	339
Average basal area	63	19	30	48	57	80	100	74	66	93	115	60	111

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

Table 118.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Northern Pine Unit, Minnesota, 1977[1]

Balsam fir forest type - Site index class 0-50

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)										
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	6	0	0	4	0	0	0	39	0	0	0	0	0
Red pine	13	0	0	11	0	0	8	61	0	0	0	136	0
Jack pine	7	0	0	0	0	11	33	6	0	0	0	0	0
White spruce	10	0	5	0	4	0	6	15	132	0	0	0	0
Black spruce	39	0	45	29	50	15	53	89	0	0	0	0	0
Balsam fir	191	9	48	61	79	359	208	246	721	801	0	287	0
Tamarack	28	65	17	14	18	0	92	39	0	0	0	0	0
Northern white-cedar	57	29	19	107	23	32	79	0	335	102	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	350	103	134	227	175	417	479	495	1,188	903	0	423	0
Hardwoods:													
Select white oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Select red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Soft maple	1	0	0	0	0	2	0	3	0	0	0	0	0
Ash	16	0	2	18	0	10	17	60	0	0	0	42	0
Balsam poplar	9	0	3	3	10	25	27	0	0	0	0	0	0
Paper birch	38	0	5	7	68	50	36	54	122	274	0	61	0
Bigtooth aspen	1	0	0	0	0	4	0	0	0	0	0	0	0
Quaking aspen	36	10	21	6	74	42	0	97	90	0	0	52	0
Basswood	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	3	0	1	0	0	1	5	0	24	0	0	40	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	103	10	31	34	152	133	85	214	236	274	0	194	0
Total all species	453	113	165	261	327	551	564	709	1,424	1,176	0	618	0
Number of plots	69	4	13	12	6	11	9	9	3	1	0	1	0
Standard error[3]	44	49	39	55	81	75	85	97	148	R	0	R	0
Average basal area	69	15	42	69	80	76	79	76	130	165	0	49	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 119.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Northern Pine Unit, Minnesota, 1977[1]

Balsam fir forest type - Site index class 51-60

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	10	0	0	0	0	7	11	59	0	0	0	0	0
Red pine	5	0	0	59	0	0	0	0	0	0	0	0	0
Jack pine	11	0	0	34	0	0	35	0	0	0	0	0	0
White spruce	34	0	0	0	0	38	37	136	0	0	0	0	0
Black spruce	38	0	0	0	29	31	48	63	85	0	0	0	0
Balsam fir	512	0	99	60	64	554	779	593	599	0	0	0	0
Tamarack	41	0	0	70	74	0	55	237	0	0	0	0	0
Northern white-cedar	73	0	0	91	143	4	21	0	492	0	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	723	0	99	315	310	633	986	1,088	1,177	0	0	0	0
Hardwoods:													
Select white oaks	1	0	0	0	0	4	0	0	0	0	0	0	0
Select red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Soft maple	4	0	0	7	0	3	0	0	24	0	0	0	0
Ash	14	47	0	0	47	4	33	0	11	0	0	0	0
Balsam poplar	67	0	0	0	16	123	7	0	188	0	0	0	0
Paper birch	108	0	0	218	114	72	147	211	63	0	0	0	0
Bigtooth aspen	0	0	0	0	0	0	0	0	0	0	0	0	0
Quaking aspen	97	0	0	0	0	178	47	47	157	0	0	0	0
Basswood	5	0	0	18	0	9	0	0	0	0	0	0	0
Elm	12	0	51	0	0	16	13	0	0	0	0	0	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	308	47	51	243	177	407	247	259	443	0	0	0	0
Total all species	1,031	47	150	558	487	1,041	1,233	1,347	1,620	0	0	0	0
Number of plots	38	1	2	3	2	14	9	3	4	0	0	0	0
Standard error[3]	106	R	150	157	11	166	151	92	497	0	0	0	0
Average basal area	99	8	21	81	79	99	119	90	147	0	0	0	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 120.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Northern Pine Unit. Minnesota, 1977[1]

Balsam fir forest type - Site index class 61-70

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	16	0	0	0	0	0	79	21	0	0	0	0	0
Red pine	80	49	0	0	43	26	394	20	0	0	0	0	0
Jack pine	5	39	0	0	0	0	0	0	0	0	0	0	0
White spruce	39	0	0	0	121	26	26	0	0	0	0	0	0
Black spruce	35	37	0	161	21	102	0	0	0	0	0	0	0
Balsam fir	670	169	0	292	473	866	420	1,239	0	0	0	0	0
Tamarack	26	0	0	0	24	0	149	0	0	0	0	0	0
Northern white-cedar	5	0	0	0	0	41	0	0	0	0	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	877	294	0	453	682	1,061	1,067	1,281	0	0	0	0	0
Hardwoods:													
Select white oaks	11	0	0	0	0	0	0	41	0	0	0	0	0
Select red oaks	3	0	0	0	0	22	0	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Soft maple	4	0	0	0	0	0	0	15	0	0	0	0	0
Ash	5	0	0	0	19	0	0	0	0	0	0	0	0
Balsam poplar	80	0	0	0	129	0	0	170	0	0	0	0	0
Paper birch	207	30	0	330	148	457	224	190	0	0	0	0	0
Bigtooth aspen	0	0	0	0	0	0	0	0	0	0	0	0	0
Quaking aspen	171	30	0	0	94	308	406	176	0	0	0	0	0
Basswood	5	0	0	0	0	0	0	19	0	0	0	0	0
Elm	5	0	0	0	0	0	0	17	0	0	0	0	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	490	61	0	330	389	787	630	628	0	0	0	0	0
Total all species	1,367	355	0	782	1,072	1,848	1,697	1,908	0	0	0	0	0
Number of plots	15	2	0	1	4	2	2	4	0	0	0	0	0
Standard error[3]	194	257	0	R	151	451	687	361	0	0	0	0	0
Average basal area	109	36	0	139	83	156	154	118	0	0	0	0	0

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[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 121.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Northern Pine Unit Minnesota, 1977[1]

Balsam fir forest type - All site index classes

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	9	0	0	3	0	4	11	40	0	0	0	0	0
Red pine	18	12	0	16	14	2	42	35	0	0	0	136	0
Jack pine	9	10	0	5	0	4	38	3	0	0	0	0	0
White spruce	26	0	4	0	42	38	35	30	56	0	0	0	0
Black spruce	40	9	39	59	37	29	40	55	49	0	0	0	0
Balsam fir	375	70	55	176	208	515	467	639	652	801	0	287	0
Tamarack	30	32	15	22	29	0	71	59	0	0	0	0	0
Northern white-cedar	56	14	16	82	35	24	43	16	425	102	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	562	148	129	363	367	615	746	877	1,181	903	0	423	0
Hardwoods:													
Select white oaks	4	0	0	0	0	9	2	12	0	0	0	0	0
Select red oaks	0	0	0	0	0	2	0	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Soft maple	2	0	0	1	0	2	3	5	14	0	0	0	0
Ash	13	6	2	11	14	6	22	30	6	0	0	42	0
Balsam poplar	35	0	3	2	51	74	13	43	107	0	0	0	0
Paper birch	89	52	4	92	102	88	99	146	88	274	0	61	0
Bigtooth aspen	0	0	0	0	0	2	0	0	0	0	0	0	0
Quaking aspen	78	13	18	52	68	132	66	108	128	0	0	52	0
Basswood	5	0	0	3	0	4	0	26	0	0	0	0	0
Elm	6	0	7	0	0	10	7	4	10	0	0	40	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	233	71	34	161	235	328	212	373	354	274	0	194	0
Total all species	794	219	163	524	602	943	958	1,250	1,536	1,176	0	618	0
Number of plots	132	8	15	19	12	28	23	18	7	1	0	1	0
Standard error[3]	58	82	36	149	118	120	112	171	274	R	0	R	0
Average basal area	84	24	39	81	81	94	101	94	139	165	0	49	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 122.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Northern Pine Unit, Minnesota, 1977[1]

Northern white-cedar forest type - Site index class 0-50

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	1	0	0	0	0	21	0	0	0	0	0	0	2
Red pine	0	0	0	0	0	0	0	0	0	0	0	0	0
Jack pine	1	0	0	0	0	0	7	0	0	0	0	0	0
White spruce	3	0	0	11	0	0	0	8	6	1	0	0	2
Black spruce	68	0	0	51	180	98	69	117	5	88	54	65	47
Balsam fir	42	0	61	10	128	26	77	42	51	29	9	35	45
Tamarack	45	0	96	5	0	37	31	97	34	45	44	31	41
Northern white-cedar	442	220	43	166	304	258	372	310	343	480	590	404	744
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	602	220	200	243	612	441	556	575	439	643	697	535	881
Hardwoods:													
Select white oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Select red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Soft maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	18	0	0	0	0	107	0	7	28	34	0	5	33
Balsam poplar	12	0	0	3	0	17	39	20	22	0	4	11	3
Paper birch	30	0	0	4	48	144	24	15	84	1	53	13	38
Bigtooth aspen	0	0	0	0	0	0	0	0	0	0	0	0	0
Quaking aspen	5	0	0	0	0	0	0	11	11	3	10	4	6
Basswood	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	0	0	0	0	0	0	0	0	0	0	0	0	2
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	65	0	0	7	48	268	63	52	146	37	68	31	82
Total all species	667	220	200	250	661	709	619	628	585	680	765	566	963
Number of plots	121	1	2	6	3	3	11	19	11	16	8	18	23
Standard error[3]	46	R	104	76	362	282	97	71	154	114	231	105	139
Average basal area	118	71	47	68	107	136	115	112	95	134	120	123	140

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 123.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Northern Pine Unit, Minnesota, 1977[1]

Northern white-cedar forest type - All site index classes

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years) 0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	1	0	0	0	0	21	0	0	0	0	0	0	2
Red pine	0	0	0	0	0	0	0	0	0	0	0	0	0
Jack pine	1	0	0	0	0	0	6	0	0	0	0	0	0
White spruce	3	0	0	11	0	0	0	7	6	1	0	0	2
Black spruce	71	0	0	51	180	98	67	127	5	88	54	65	47
Balsam fir	46	0	61	10	128	26	89	60	51	29	9	35	45
Tamarack	45	0	96	5	0	37	38	88	34	45	44	31	41
Northern white-cedar	442	220	43	166	304	258	355	336	343	480	590	404	744
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	609	220	200	243	612	441	555	618	439	643	697	535	881
Hardwoods:													
Select white oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Select red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Soft maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	17	0	0	0	0	107	0	7	28	34	0	5	33
Balsam poplar	12	0	0	3	0	17	41	18	22	0	4	11	3
Paper birch	29	0	0	4	48	144	22	13	84	1	53	13	38
Bigtooth aspen	0	0	0	0	0	0	0	0	0	0	0	0	0
Quaking aspen	5	0	0	0	0	0	0	10	11	3	10	4	6
Basswood	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	0	0	0	0	0	0	0	0	0	0	0	0	2
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	64	0	0	7	48	268	63	47	146	37	68	31	82
Total all species	673	220	200	250	661	709	618	665	585	680	765	566	963
Number of plots	124	1	2	6	3	3	12	21	11	16	8	18	23
Standard error[3]	45	R	104	76	362	282	88	69	154	114	231	105	139
Average basal area	118	71	47	168	107	136	110	113	95	134	120	123	140

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 124.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Northern Pine Unit, Minnesota, 1977[1]

Tamarack forest type - Site index class 0-50

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)										
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:												
White pine	2	0	0	0	0	3	3	0	16	3	0	0	0
Red pine	2	0	0	0	0	0	0	0	21	3	0	0	0
Jack pine	4	0	0	0	0	29	0	34	0	0	0	7	0
White spruce	1	0	0	0	0	5	5	0	3	0	0	0	0
Black spruce	44	4	10	24	39	73	72	34	63	39	0	89	60
Balsam fir	8	0	0	0	0	0	20	31	38	9	0	0	0
Tamarack	319	82	109	112	112	243	296	428	350	421	878	605	547
Northern white-cedar	13	0	0	10	0	0	34	0	7	17	0	15	45
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	393	86	120	147	151	353	431	526	498	490	878	716	652
Hardwoods:												
Select white oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Select red oaks	0	4	0	0	0	0	0	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Soft maple	0	0	0	0	0	0	0	0	5	0	0	0	0
Ash	0	0	0	0	0	0	0	0	0	3	0	0	0
Balsam poplar	3	0	1	0	0	0	0	35	2	0	0	0	11
Paper birch	8	0	0	4	5	0	20	28	38	2	0	2	3
Bigtooth aspen	0	0	0	0	0	0	0	0	0	0	0	0	0
Quaking aspen	2	0	0	0	3	0	0	0	9	0	0	0	6
Basswood	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	2	0	0	3	0	0	0	5	10	3	0	0	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	16	4	2	7	7	0	20	68	64	8	0	2	21
Total all species	409	90	121	154	158	353	451	594	562	499	878	718	673
Number of plots	154	12	23	13	9	8	16	7	14	17	4	17	14
Standard error	29	33	33	36	44	90	69	152	109	64	219	79	88
Average basal area	55	27	36	43	46	66	57	54	70	60	82	68	69

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

Table 125.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Northern Pine Unit, Minnesota 1977[1]

Tamarack forest type - Site index class 51-60

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	3	0	15	0	0	0	0	0	22	0	0	0	0
Red pine	0	0	0	0	0	0	0	0	0	0	0	0	0
Jack pine	0	0	0	0	0	0	0	0	0	0	0	0	0
White spruce	2	0	0	0	0	0	4	0	0	0	0	0	0
Black spruce	50	0	38	0	0	150	39	230	56	0	0	0	0
Balsam fir	9	0	0	9	0	0	15	0	19	0	0	0	0
Tamarack	650	0	96	170	1,116	734	855	1,055	744	0	0	1,152	0
Northern white-cedar	2	0	0	0	0	0	0	0	33	0	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	716	0	149	179	1,116	883	912	1,285	874	0	0	1,152	0
Hardwoods:													
Select white oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Select red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Soft maple	1	0	0	4	0	0	0	0	0	0	0	0	0
Ash	8	0	0	0	0	0	0	0	106	0	0	0	0
Balsam poplar	0	0	0	0	0	0	0	0	0	0	0	0	0
Paper birch	5	0	0	0	0	0	12	0	0	0	0	0	0
Bigtooth aspen	0	0	0	0	0	0	0	0	0	0	0	0	0
Quaking aspen	18	0	94	31	0	0	4	0	0	0	0	0	0
Basswood	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	0	0	0	0	0	0	0	0	0	0	0	0	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	32	0	94	36	0	0	17	0	106	0	0	0	0
Total all species	748	0	243	214	1,116	883	929	1,285	980	0	0	1,152	0
Number of plots	27	0	3	5	1	3	11	1	2	0	0	1	0
Standard error[3]	109	0	121	104	R	278	196	R	186	0	0	R	0
Average basal area	58	0	45	26	82	60	68	90	75	0	0	60	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 126.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Northern Pine Unit, Minnesota, 1977[1]

Tamarack forest type - All site index classes

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	3	0	2	0	0	2	2	0	17	6	0	0	0
Red pine	2	0	0	0	0	0	0	0	18	3	0	0	0
Jack pine	3	0	0	0	0	19	0	29	0	0	0	7	0
White spruce	1	0	0	0	0	3	6	0	3	0	0	0	0
Black spruce	45	4	13	18	45	86	56	59	63	42	0	84	60
Balsam fir	8	0	0	2	0	0	16	27	35	8	0	0	0
Tamarack	379	82	120	128	262	464	532	506	399	420	878	635	547
Northern white-cedar	11	0	0	8	0	0	18	0	10	16	0	14	45
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	451	86	134	156	308	575	630	621	545	495	878	740	652
Hardwoods:													
Select white oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Select red oaks	0	4	0	0	0	0	0	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Soft maple	1	0	0	1	0	0	0	0	5	0	0	0	0
Ash	1	0	0	0	0	0	0	0	13	3	0	0	0
Balsam poplar	8	0	8	0	0	0	28	31	2	0	0	0	11
Paper birch	8	0	2	3	4	0	15	24	33	2	0	2	3
Bigtooth aspen	0	0	0	0	0	0	0	0	0	0	0	0	0
Quaking aspen	6	0	12	9	2	0	14	0	8	0	0	0	6
Basswood	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	2	0	0	2	0	0	3	4	8	3	0	0	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	26	4	23	15	6	0	59	59	70	8	0	2	21
Total all species	477	90	156	170	314	575	689	680	615	503	878	742	673
Number of plots	189	12	28	18	11	12	30	8	16	18	4	18	14
Standard error	30	33	35	38	111	133	93	157	103	60	219	79	88
Average basal area	56	27	42	38	52	66	63	59	71	59	82	68	69

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

Table 127.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Northern Pine Unit, Minnesota, 1977[1]

White spruce forest type - All site index classes

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	39	0	0	0	0	0	0	48	0	375	0	0	0
Red pine	30	0	126	0	0	0	0	117	0	0	0	0	0
Jack pine	103	0	0	62	0	0	126	239	0	0	0	0	0
White spruce	240	0	0	55	0	0	384	294	0	266	0	0	0
Black spruce	19	0	0	0	0	0	0	114	0	0	0	0	0
Balsam fir	90	0	0	48	0	0	94	238	0	33	0	0	0
Tamarack	16	0	0	0	0	0	0	97	0	0	0	0	0
Northern white-cedar	33	0	0	0	0	0	43	0	0	179	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	570	0	126	165	0	0	647	1,147	0	853	0	0	0
Hardwoods:													
Select white oaks	2	0	0	0	0	0	0	0	0	23	0	0	0
Select red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Soft maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	0	0	0	0	0	0	0	0	0	0	0	0	0
Balsam poplar	33	0	0	0	0	0	20	122	0	58	0	0	0
Paper birch	24	0	0	0	0	0	12	33	0	158	0	0	0
Bigtooth aspen	0	0	0	0	0	0	0	0	0	0	0	0	0
Quaking aspen	95	0	0	94	0	0	181	0	0	51	0	0	0
Basswood	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	0	0	0	0	0	0	0	0	0	0	0	0	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	154	0	0	94	0	0	212	155	0	290	0	0	0
Total all species	724	0	126	259	0	0	859	1,302	0	1,143	0	0	0
Number of plots	12	1	1	2	0	0	5	2	0	1	0	0	0
Standard error[3]	176	R	R	259	0	0	239	523	0	R	0	0	0
Average basal area	71	0	11	58	0	0	88	77	0	128	0	0	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 128.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Northern Pine Unit, Minnesota, 1977[1]

Oak-hickory forest type - Site index class 0-50

(In cubic feet per acre)

Species	Average[2]	0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
		Stand-age class (years)											
Softwoods:													
White pine	3	2	0	0	0	0	0	0	5	18	12	14	0
Red pine	22	7	12	0	0	29	44	0	10	0	0	138	0
Jack pine	28	13	30	0	173	42	23	7	24	0	0	0	0
White spruce	3	0	0	0	0	0	3	12	0	0	0	10	0
Black spruce	1	0	0	0	0	0	0	0	5	0	0	0	0
Balsam fir	2	0	0	0	0	21	0	0	0	0	0	0	0
Tamarack	1	0	0	0	0	0	0	0	5	0	0	0	0
Northern white-cedar	0	0	0	0	0	0	0	0	0	0	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	60	23	42	0	173	91	70	19	50	18	12	163	0
Hardwoods:													
Select white oaks	148	12	77	153	33	138	77	204	248	320	322	83	0
Select red oaks	188	50	5	0	226	124	296	242	183	235	219	130	0
Other red oaks	0	0	0	0	0	5	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	0	0	0	0	0	0	0	0	0	0	4	0	0
Soft maple	3	0	0	0	0	13	0	2	0	0	17	0	0
Ash	9	0	9	0	0	0	0	9	17	10	55	0	0
Balsam poplar	5	0	0	0	56	0	0	13	0	0	0	0	0
Paper birch	48	8	20	0	0	100	51	106	37	28	34	14	0
Bigtooth aspen	8	4	0	0	27	34	3	0	15	0	0	0	0
Quaking aspen	74	0	47	0	13	79	103	71	127	38	40	130	0
Basswood	21	0	0	0	0	43	6	12	40	44	76	0	0
Elm	9	0	12	0	0	5	15	16	11	15	2	0	0
Select hardwoods	1	0	0	0	0	0	0	0	8	0	0	0	0
Other hardwoods	1	0	0	0	0	0	0	0	0	0	9	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	515	74	170	153	356	541	551	673	686	690	779	356	0
Total all species	575	96	213	153	529	632	620	691	736	708	791	519	0
Number of plots	83	7	6	1	5	9	18	11	12	4	6	4	0
Standard error[3]	38	38	85	R	136	119	57	135	86	148	96	74	0
Average basal area	72	22	45	45	75	77	81	78	85	86	87	59	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 129.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Northern Pine Unit, Minnesota, 1977[1]

Oak-hickory forest type - Site index class 51-60

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	11	0	0	0	0	0	12	0	83	0	0	0	0
Red pine	17	0	0	0	0	4	14	37	69	0	0	0	0
Jack pine	45	95	41	0	0	49	0	130	0	0	0	0	0
White spruce	1	0	0	0	0	3	0	0	0	0	0	0	0
Black spruce	0	0	0	0	0	0	0	0	0	0	0	0	0
Balsam fir	0	0	0	0	0	0	0	0	0	0	0	0	0
Tamarack	0	0	0	0	0	0	0	0	0	0	0	0	0
Northern white-cedar	0	0	0	0	0	0	0	0	0	0	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	74	95	41	0	0	56	26	168	152	0	0	0	0
Hardwoods:													
Select white oaks	83	0	29	0	94	80	78	45	142	0	410	0	0
Select red oaks	453	0	71	0	51	420	671	663	658	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	6	0	0	0	0	4	16	9	0	0	0	0	0
Soft maple	9	0	0	0	0	0	25	14	18	0	0	0	0
Ash	6	0	0	0	30	3	19	0	0	0	0	0	0
Balsam poplar	0	0	0	0	0	0	0	0	0	0	0	0	0
Paper birch	144	0	27	0	22	59	256	406	102	0	0	0	0
Bigtooth aspen	48	0	0	0	0	37	64	77	101	0	0	0	0
Quaking aspen	103	0	0	0	173	100	190	40	145	0	0	0	0
Basswood	42	0	0	0	54	7	66	108	11	0	294	0	0
Elm	13	0	0	0	30	7	13	5	7	0	222	0	0
Select hardwoods	9	0	0	0	90	5	6	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	916	0	128	0	544	723	1,406	1,367	1,185	0	926	0	0
Total all species	991	95	169	0	544	779	1,431	1,534	1,337	0	926	0	0
Number of plots	45	2	3	0	3	16	8	7	5	0	1	0	0
Standard error[3]	92	95	44	0	170	78	238	233	174	0	R	0	0
Average basal area	94	12	47	0	71	80	128	119	125	0	82	0	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 130.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Northern Pine Unit, Minnesota, 1977[1]

Oak-hickory forest type - Site index class 61-70

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)										
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	4	0	0	0	0	10	0	0	0	0	0	0	0
Red pine	6	0	174	0	0	0	0	0	0	0	0	0	0
Jack pine	0	0	0	0	0	0	0	0	0	0	0	0	0
White spruce	0	0	0	0	0	0	0	0	0	0	0	0	0
Black spruce	0	0	0	0	0	0	0	0	0	0	0	0	0
Balsam fir	5	0	0	22	0	0	0	14	0	0	0	0	0
Tamarack	3	0	0	0	0	9	0	0	0	0	0	0	0
Northern white-cedar	0	0	0	0	0	0	0	0	0	0	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	18	0	174	22	0	19	0	14	0	0	0	0	0
Hardwoods:													
Select white oaks	131	0	0	54	98	182	63	232	62	0	0	0	0
Select red oaks	510	0	412	92	291	649	532	545	1,168	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	14	0	0	0	28	10	17	33	0	0	0	0	0
Soft maple	30	0	0	9	24	57	0	30	0	0	0	0	0
Ash	12	0	0	0	14	29	0	0	0	0	0	0	0
Balsam poplar	3	0	0	0	0	7	0	0	0	0	0	0	0
Paper birch	141	0	125	47	63	192	168	161	0	0	0	0	0
Bigtooth aspen	45	0	0	0	0	41	138	39	0	0	0	0	0
Quaking aspen	127	0	0	0	225	128	229	117	0	0	0	0	0
Basswood	36	0	0	0	105	44	26	26	0	0	0	0	0
Elm	12	0	0	0	0	24	0	18	0	0	0	0	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	1,061	0	537	202	849	1,363	1,173	1,201	1,230	0	0	0	0
Total all species	1,079	0	711	224	849	1,382	1,173	1,214	1,230	0	0	0	0
Number of plots	29	0	1	4	3	11	5	4	1	0	0	0	0
Standard error[3]	103	0	R	67	230	135	289	109	R	0	0	0	0
Average basal area	94	0	86	35	76	113	92	119	94	0	0	0	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 131.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Northern Pine Unit, Minnesota, 1977[1]

Oak-hickory forest type - All site index classes

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)										
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	5	2	0	0	0	3	3	0	27	14	10	11	0
Red pine	17	6	22	0	0	8	26	12	26	0	0	130	0
Jack pine	27	32	49	0	62	30	12	45	16	0	0	0	0
White spruce	2	0	0	0	0	1	2	6	0	0	0	8	0
Black spruce	0	0	0	0	0	0	0	0	4	0	0	0	0
Balsam fir	2	0	0	18	0	5	0	2	0	0	0	0	0
Tamarack	1	0	0	0	0	2	0	0	4	0	0	0	0
Northern white-cedar	0	0	0	0	0	0	0	0	0	0	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	54	39	72	18	62	49	43	65	76	14	10	150	0
Hardwoods:													
Select white oaks	123	10	50	74	70	116	68	159	208	288	335	196	0
Select red oaks	354	39	60	74	263	462	484	431	370	256	188	304	0
Other red oaks	0	0	0	0	0	1	0	0	0	0	0	0	0
Hickory	1	0	0	0	0	2	2	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	5	0	0	0	10	4	10	9	0	0	3	0	0
Soft maple	12	0	0	7	10	20	15	11	5	0	14	12	0
Ash	8	0	5	0	9	9	4	4	11	8	47	0	0
Balsam poplar	3	0	0	0	20	2	0	6	0	0	0	0	0
Paper birch	94	6	30	37	54	111	123	211	53	36	29	32	0
Bigtooth aspen	26	3	0	0	10	43	37	31	38	0	0	0	0
Quaking aspen	94	0	36	0	96	103	147	69	125	104	35	123	0
Basswood	36	0	0	0	34	55	28	45	30	43	108	0	0
Elm	10	0	7	0	10	11	11	13	9	12	34	0	0
Select hardwoods	4	0	0	0	19	2	7	0	5	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	8	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	771	57	187	192	606	941	936	990	854	746	800	668	0
Total all species	826	96	259	210	668	990	979	1,055	930	761	811	817	0
Number of plots	169	9	11	5	14	39	34	22	18	5	7	5	0
Standard error	43	33	66	54	89	87	103	128	98	126	83	304	0
Average basal area	83	20	51	37	74	91	96	98	96	85	86	75	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

Table 132.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Northern Pine Unit, Minnesota, 1977[1]

Elm-ash-cottonwood forest type - Site index class 0-50

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)										
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	1	0	0	0	0	0	0	0	6	6	0	0	0
Red pine	1	0	0	0	0	0	0	0	0	5	0	0	0
Jack pine	0	0	0	0	0	0	0	0	0	0	0	0	0
White spruce	3	0	0	0	0	0	17	0	5	6	0	0	0
Black spruce	4	0	0	5	0	0	0	0	4	13	0	9	0
Balsam fir	37	0	23	11	81	44	44	19	35	39	64	76	0
Tamarack	4	0	0	9	0	0	0	0	0	18	0	6	0
Northern white-cedar	39	26	0	10	0	0	30	14	17	51	43	202	0
Other softwoods	1	0	0	0	0	0	0	0	7	0	0	0	0
Total	89	26	23	35	81	44	92	32	75	137	107	292	0
Hardwoods:													
Select white oaks	9	0	0	3	0	11	36	0	0	19	33	0	0
Select red oaks	1	0	0	0	0	0	0	11	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	3	0	0	0	0	0	0	0	0	0
Hard maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Soft maple	16	0	0	0	0	0	0	0	5	0	0	0	456
Ash	263	108	142	140	90	274	342	451	292	279	357	410	304
Balsam poplar	25	27	0	13	40	26	32	36	63	7	0	22	54
Paper birch	32	0	19	10	24	43	34	23	72	32	20	76	0
Bigtooth aspen	1	0	0	0	0	0	6	0	0	0	0	0	0
Quaking aspen	24	0	0	19	21	40	74	52	48	11	0	0	0
Basswood	29	0	0	0	0	0	49	89	5	98	0	25	70
Elm	62	0	29	19	11	12	99	56	112	93	40	64	265
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	1	0	0	0	0	0	0	0	0	5	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	462	135	190	206	187	405	672	717	596	544	451	597	1,149
Total all species	552	162	213	241	268	449	763	750	671	682	559	890	1,149
Number of plots	87	5	6	14	6	4	9	6	9	11	5	9	3
Standard error	46	42	69	51	90	143	131	196	94	105	95	202	430
Average basal area	74	19	55	51	57	76	85	92	98	74	87	104	104

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

Table 133.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Northern Pine Unit, Minnesota, 1977[1]

Elm-ash-cottonwood forest type - Site index class 51-60

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	1	0	0	0	0	0	8	0	0	0	0	0	0
Red pine	0	0	0	0	0	0	0	0	0	0	0	0	0
Jack pine	2	0	0	0	0	0	0	14	0	0	0	0	0
White spruce	9	0	0	0	0	9	8	34	15	0	0	0	0
Black spruce	0	0	0	0	0	0	0	0	0	0	0	0	0
Balsam fir	48	0	94	0	0	0	63	53	81	10	81	165	0
Tamarack	8	100	0	0	0	0	0	0	0	0	0	0	0
Northern white-cedar	28	0	0	0	0	0	27	0	9	37	165	308	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	97	100	94	0	0	9	106	100	106	47	246	473	0
Hardwoods:													
Select white oaks	10	0	0	0	0	0	20	17	8	30	0	0	0
Select red oaks	4	0	0	0	0	0	10	0	17	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	7	0	0	0	0	0	11	0	10	37	0	0	0
Hard maple	7	0	0	0	0	0	39	0	5	0	0	0	0
Soft maple	12	0	0	0	0	3	38	0	36	0	0	0	0
Ash	517	83	137	141	599	560	534	503	681	820	564	711	720
Balsam poplar	44	22	26	0	42	74	45	10	16	24	185	0	72
Paper birch	70	0	0	0	0	72	59	48	155	0	168	476	0
Bigtooth aspen	0	0	0	0	0	0	0	0	0	0	0	0	0
Quaking aspen	47	46	0	0	0	99	34	81	45	55	19	59	0
Basswood	11	0	8	77	0	6	22	0	29	5	0	0	0
Elm	121	17	6	0	22	134	66	141	271	92	75	37	972
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	1	0	0	0	0	0	0	5	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	850	169	176	219	663	949	878	804	1,272	1,063	1,010	1,283	1,763
Total all species	947	268	270	219	663	958	984	904	1,378	1,110	1,255	1,755	1,763
Number of plots	61	5	5	1	2	7	10	9	9	6	5	1	1
Standard error[3]	76	98	74	R	345	188	149	124	160	87	514	R	R
Average basal area	86	29	35	45	83	88	102	82	105	96	114	128	124

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 134.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Northern Pine Unit, Minnesota, 1977[1]

Elm-ash-cottonwood forest type - Site index class 61-70

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)										
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	2	0	0	0	0	0	0	8	0	0	0	0	0
Red pine	0	0	0	0	0	0	0	0	0	0	0	0	0
Jack pine	0	0	0	0	0	0	0	0	0	0	0	0	0
White spruce	0	0	0	0	0	0	0	0	0	0	0	0	0
Black spruce	0	0	0	0	0	0	0	0	0	0	0	0	0
Balsam fir	55	0	0	0	66	0	70	55	33	89	0	18	200
Tamarack	6	0	0	0	0	0	13	10	0	0	0	0	0
Northern white-cedar	43	0	0	0	232	0	22	26	0	0	0	172	158
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	107	0	0	0	298	0	104	99	33	89	0	190	358
Hardwoods:													
Select white oaks	19	0	0	0	0	72	6	20	78	24	0	0	0
Select red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	4	0	0	0	0	0	0	15	0	0	0	0	0
Soft maple	56	0	74	0	0	0	117	15	112	0	95	0	0
Ash	661	0	375	0	268	887	536	931	348	578	875	698	1,161
Balsam poplar	70	0	0	0	90	0	138	45	113	26	0	0	0
Paper birch	48	0	81	0	0	0	65	52	34	54	0	54	42
Bigtooth aspen	20	0	0	0	0	0	0	8	0	0	0	225	0
Quaking aspen	46	0	68	0	159	0	52	57	0	74	0	0	0
Basswood	16	0	0	0	0	197	6	21	0	43	0	0	0
Elm	155	0	0	0	51	86	101	149	378	72	247	294	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	2	0	0	0	0	0	0	6	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	1,097	0	598	0	568	1,242	1,021	1,317	1,063	871	1,217	1,271	1,203
Total all species	1,204	0	598	0	866	1,242	1,125	1,416	1,095	961	1,217	1,462	1,560
Number of plots	38	0	1	0	2	1	11	10	4	3	2	3	1
Standard error[3]	79	0	R	0	221	R	135	176	241	240	317	416	R
Average basal area	93	0	45	0	104	101	86	104	89	63	101	114	124

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 135.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Northern Pine Unit, Minnesota, 1977[1]

Elm-ash-cottonwood forest type - All site index classes

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	1	0	0	0	0	0	2	3	2	3	0	0	0
Red pine	0	0	0	0	0	0	0	0	0	3	0	0	0
Jack pine	1	0	0	0	0	0	0	5	0	0	0	0	0
White spruce	4	0	0	0	0	4	7	12	8	3	0	0	0
Black spruce	2	0	0	4	0	0	0	0	2	7	0	6	0
Balsam fir	46	0	51	11	56	25	64	46	56	36	60	69	40
Tamarack	6	50	0	8	0	0	7	4	0	9	0	4	0
Northern white-cedar	35	13	0	9	42	7	23	14	10	37	87	203	32
Other softwoods	0	0	0	0	0	0	0	0	3	0	0	0	0
Total	95	63	51	33	98	36	103	83	80	98	147	283	72
Hardwoods:													
Select white oaks	13	0	0	2	0	8	17	14	16	40	14	0	0
Select red oaks	3	0	0	0	0	0	9	3	6	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	2	0	0	2	0	0	3	0	4	11	0	0	0
Hard maple	3	0	0	0	0	0	11	6	2	0	0	0	0
Soft maple	28	0	6	0	0	10	81	6	34	0	16	0	274
Ash	433	96	159	140	237	547	456	661	475	494	530	500	558
Balsam poplar	47	25	11	13	75	51	81	30	77	14	77	16	47
Paper birch	51	0	16	9	13	100	55	44	91	25	78	102	8
Bigtooth aspen	4	0	0	0	0	0	4	3	0	0	0	52	0
Quaking aspen	35	23	6	18	40	57	53	64	35	32	8	5	0
Basswood	24	0	3	5	0	24	28	30	12	83	0	17	42
Elm	102	9	17	18	23	98	93	124	216	95	89	115	353
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	1	0	0	0	0	0	0	4	0	2	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	744	152	218	207	388	894	892	988	968	796	812	806	1,282
Total all species	839	215	269	239	487	930	996	1,072	1,048	894	959	1,088	1,354
Number of plots	197	10	12	15	11	15	34	25	24	21	12	13	5
Standard error	41	53	54	48	107	141	74	109	118	88	231	182	269
Average basal area	83	24	46	50	74	87	93	93	97	80	101	108	112

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

Table 136.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Northern Pine Unit, Minnesota, 1977[1]

Maple-basswood forest type - Site index class 0-50

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years) 0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	13	0	61	0	0	15	0	25	16	0	9	39	0
Red pine	0	0	0	0	0	0	0	0	0	0	0	0	0
Jack pine	1	0	0	0	0	5	0	0	0	0	0	0	0
White spruce	4	0	0	0	0	0	0	13	0	0	0	12	26
Black spruce	1	0	0	0	0	7	0	0	0	0	0	0	0
Balsam fir	52	0	0	0	41	39	48	78	57	73	73	154	0
Tamarack	1	0	0	0	0	7	0	0	0	0	0	0	0
Northern white-cedar	1	0	0	0	0	0	0	0	12	0	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	73	0	61	0	41	73	48	116	85	73	82	205	26
Hardwoods:													
Select white oaks	33	0	0	0	14	26	77	61	118	0	5	0	81
Select red oaks	34	0	19	0	20	4	54	46	31	4	4	28	27
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	8	0	0	0	0	0	0	0	4	0	29	100	0
Hard maple	91	76	72	30	0	15	89	39	135	111	176	159	189
Soft maple	26	0	84	0	0	16	31	28	10	0	81	62	0
Ash	67	0	34	48	0	46	135	98	38	41	100	59	41
Balsam poplar	17	0	0	0	0	20	20	81	0	0	7	0	0
Paper birch	57	0	55	67	58	68	58	35	87	79	27	112	22
Bigtooth aspen	8	0	0	0	0	0	31	5	23	0	0	0	0
Quaking aspen	52	29	0	47	0	63	35	175	37	26	6	0	53
Basswood	170	0	0	12	91	203	85	103	239	355	112	121	462
Elm	100	24	0	36	9	67	57	278	70	129	51	45	200
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	1	33	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	662	162	263	240	192	528	671	949	792	745	598	687	1,074
Total all species	735	162	325	240	232	601	719	1,065	878	818	679	892	1,100
Number of plots	74	2	3	4	2	11	10	10	9	7	8	3	5
Standard error	50	11	12	81	151	123	99	207	124	74	66	174	150
Average basal area	87	36	48	59	60	80	86	103	99	90	89	100	107

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

Table 137.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Northern Pine Unit, Minnesota, 1977[1]

Maple-basswood forest type - Site index class 51-60

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	16	0	0	0	10	7	28	7	29	0	0	0	122
Red pine	3	0	0	0	0	0	5	9	0	0	0	0	0
Jack pine	0	0	0	0	0	0	0	2	0	0	0	0	0
White spruce	6	0	0	0	28	3	3	10	11	0	0	0	0
Black spruce	0	0	0	0	0	0	0	0	0	0	0	0	0
Balsam fir	48	18	0	0	46	68	42	80	42	0	57	0	0
Tamarack	2	0	0	0	0	13	0	0	0	0	0	0	0
Northern white-cedar	3	37	0	0	0	0	1	13	0	0	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	78	55	0	0	84	91	79	119	82	0	57	0	122
Hardwoods:													
Select white oaks	47	0	0	0	19	22	47	76	92	29	11	21	175
Select red oaks	57	0	0	0	25	31	125	47	48	0	42	0	0
Other red oaks	1	0	0	0	0	0	0	4	0	0	0	0	0
Hickory	1	0	0	0	11	0	0	0	0	0	0	0	0
Yellow birch	4	0	0	0	0	3	7	3	9	0	7	0	0
Hard maple	130	0	10	0	88	55	181	105	147	149	337	187	0
Soft maple	43	0	75	38	29	30	34	62	33	0	46	290	0
Ash	100	208	97	29	58	114	71	113	127	57	147	207	72
Balsam poplar	26	65	50	0	16	29	16	14	0	301	80	0	20
Paper birch	96	61	9	55	23	146	123	131	68	0	80	24	0
Bigtooth aspen	14	0	0	0	0	0	22	37	11	0	0	0	0
Quaking aspen	68	0	12	26	126	34	81	105	70	0	55	0	0
Basswood	216	0	0	39	211	263	219	236	187	537	263	58	462
Elm	89	132	18	15	86	30	47	138	175	38	94	134	345
Select hardwoods	2	0	0	0	0	0	3	8	0	0	0	0	0
Other hardwoods	3	0	0	0	0	0	0	0	0	60	11	0	54
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	896	466	271	202	691	757	977	1,080	968	1,172	1,173	922	1,128
Total all species	975	521	271	202	775	847	1,055	1,199	1,049	1,172	1,230	922	1,250
Number of plots	115	2	4	4	9	17	31	19	15	2	8	2	2
Standard error	44	121	127	66	100	88	76	111	116	818	138	264	157
Average basal area	100	64	54	40	88	101	104	106	111	100	117	102	127

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

Table 138.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Northern Pine Unit, Minnesota, 1977[1]

Maple-basswood forest type - Site index class 61-70

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	5	0	0	0	0	6	0	7	22	0	0	0	0
Red pine	0	0	0	0	0	2	0	0	0	0	0	0	0
Jack pine	0	0	0	0	0	0	0	0	0	0	0	0	0
White spruce	2	0	0	0	24	0	0	0	0	0	0	0	0
Black spruce	0	0	0	0	0	0	0	0	0	0	0	0	0
Balsam fir	37	0	0	0	27	41	36	69	5	14	19	0	241
Tamarack	0	0	0	0	0	0	0	0	0	0	0	0	0
Northern white-cedar	0	0	0	0	0	0	0	0	0	0	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	43	0	0	0	51	48	36	76	27	14	19	0	241
Hardwoods:													
Select white oaks	52	0	0	47	0	64	56	15	97	214	14	0	0
Select red oaks	64	0	43	0	52	86	31	132	102	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	5	0	0	0	0	6	0	0	33	13	0	0	0
Hard maple	178	0	31	0	288	55	146	163	185	74	1,053	0	0
Soft maple	47	0	39	0	26	27	60	22	34	270	53	0	0
Ash	95	0	0	0	41	45	110	59	140	194	224	0	525
Balsam poplar	24	0	0	0	0	27	41	18	17	0	0	0	112
Paper birch	114	0	70	292	149	73	112	214	81	17	100	0	41
Bigtooth aspen	16	0	0	0	0	11	15	0	75	23	0	0	0
Quaking aspen	66	0	125	112	55	48	47	159	45	21	16	0	0
Basswood	328	0	15	126	45	474	413	290	327	109	365	0	0
Elm	148	0	36	0	131	69	125	220	152	354	138	0	1,075
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	4	0	0	0	0	0	2	4	0	81	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	1,143	0	360	577	787	985	1,157	1,295	1,286	1,369	1,963	0	1,753
Total all species	1,186	0	360	577	838	1,033	1,194	1,371	1,313	1,383	1,982	0	1,993
Number of plots	79	1	3	1	5	15	24	13	9	3	4	0	1
Standard error[3]	61	R	84	R	195	103	96	117	206	383	129	0	R
Average basal area	107	4	60	75	73	110	107	118	114	128	129	0	131

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 139.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Northern Pine Unit, Minnesota, 1977[1]

Maple-basswood forest type - Site index class 71-80

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	8	0	0	0	0	17	14	0	0	0	0	0	0
Red pine	4	0	0	0	0	0	13	0	0	0	0	0	0
Jack pine	0	0	0	0	0	0	0	0	0	0	0	0	0
White spruce	28	0	0	0	0	56	17	0	65	74	0	0	0
Black spruce	0	0	0	0	0	0	0	0	0	0	0	0	0
Balsam fir	87	0	0	0	0	86	136	39	230	111	0	0	0
Tamarack	0	0	0	0	0	0	0	0	0	0	0	0	0
Northern white-cedar	25	0	0	0	0	57	0	0	0	161	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	152	0	0	0	0	216	181	39	296	346	0	0	0
Hardwoods:													
Select white oaks	8	0	0	0	0	0	6	0	41	25	43	0	0
Select red oaks	53	0	0	0	76	70	45	11	0	0	428	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	5	0	0	0	0	0	10	19	0	0	0	0	0
Hard maple	249	0	0	0	288	64	256	294	358	0	558	787	624
Soft maple	31	0	0	0	64	0	69	39	0	0	0	0	0
Ash	98	0	0	0	0	80	70	227	105	0	0	0	590
Balsam poplar	12	0	0	0	0	12	0	24	80	0	0	0	0
Paper birch	216	0	0	0	303	188	230	105	248	490	297	0	0
Bigtooth aspen	11	0	0	0	0	0	41	0	0	0	0	0	0
Quaking aspen	89	0	0	0	89	205	80	0	0	112	0	0	0
Basswood	454	0	0	0	480	373	512	366	246	752	1,242	122	212
Elm	149	0	0	0	16	171	13	271	179	410	106	0	601
Select hardwoods	2	0	0	0	0	0	0	15	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	1,377	0	0	0	1,316	1,163	1,332	1,371	1,257	1,788	2,673	909	2,028
Total all species	1,529	0	0	0	1,316	1,379	1,513	1,410	1,553	2,135	2,673	909	2,028
Number of plots	29	0	0	0	3	7	8	4	2	2	1	1	1
Standard error[3]	104	0	0	0	132	197	124	204	266	1,109	R	R	R
Average basal area	118	0	0	0	117	116	118	107	113	152	150	98	112

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 140.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Northern Pine Unit, Minnesota, 1977[1]

Maple-basswood forest type - All site index classes

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	11	0	18	0	8	9	13	10	21	0	3	20	27
Red pine	1	0	0	0	0	1	3	4	0	0	0	0	0
Jack pine	0	0	0	0	0	1	0	1	0	0	0	0	0
White spruce	6	0	0	0	15	8	3	7	8	10	0	6	14
Black spruce	0	0	0	0	0	1	0	0	0	0	0	0	0
Balsam fir	49	7	0	0	44	55	49	73	46	52	53	77	27
Tamarack	1	0	0	0	0	6	0	0	0	0	0	0	0
Northern white-cedar	5	15	0	0	12	8	1	5	3	21	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	75	22	18	0	79	88	69	99	78	83	57	103	68
Hardwoods:													
Select white oaks	40	0	0	5	12	30	49	49	73	50	11	7	84
Select red oaks	54	0	19	0	31	60	76	68	75	2	38	14	15
Other red oaks	0	0	0	0	0	0	0	2	0	0	0	0	0
Hickory	0	0	0	0	4	0	0	0	0	0	0	0	0
Yellow birch	6	0	0	0	5	4	4	3	13	3	14	50	0
Hard maple	146	30	35	13	139	60	167	123	169	116	422	273	174
Soft maple	39	0	67	17	47	20	46	41	25	54	58	128	0
Ash	91	83	49	34	53	71	96	104	111	66	137	99	162
Balsam poplar	21	26	20	0	8	23	22	31	9	40	33	0	17
Paper birch	106	24	41	87	105	122	126	131	84	130	74	64	17
Bigtooth aspen	13	0	0	0	14	5	22	16	29	5	0	0	0
Quaking aspen	70	12	42	45	131	75	62	126	50	31	26	0	30
Basswood	270	0	5	37	205	319	329	234	255	445	272	101	383
Elm	114	63	18	23	94	68	78	203	144	190	87	67	374
Select hardwoods	1	0	0	0	0	0	1	5	0	0	0	0	0
Other hardwoods	2	13	0	0	0	0	1	1	0	24	4	0	12
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	975	251	295	261	849	856	1,080	1,138	1,036	1,155	1,176	802	1,267
Total all species	1,050	273	314	261	928	945	1,149	1,237	1,115	1,238	1,232	905	1,336
Number of plots	310	5	10	9	24	53	76	46	36	15	21	6	9
Standard error	32	112	53	58	91	63	60	74	83	202	140	104	154
Average basal area	101	41	54	52	93	102	105	109	109	111	110	100	115

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

Table 141.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Northern Pine Unit, Minnesota, 1977[1]

Aspen forest type - Site index class 0-50

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	1	0	0	0	0	0	0	6	0	0	0	0	0
Red pine	20	0	0	0	39	7	0	129	13	0	0	0	0
Jack pine	16	20	8	0	0	0	30	49	0	0	0	0	0
White spruce	4	1	0	8	8	0	0	24	0	0	0	0	0
Black spruce	2	0	0	0	20	0	0	0	0	0	0	0	0
Balsam fir	34	0	6	39	61	3	75	88	0	180	46	0	72
Tamarack	1	0	0	0	0	0	0	0	0	48	0	0	0
Northern white-cedar	3	0	0	24	0	0	0	9	0	34	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	81	22	15	70	127	10	105	305	13	262	46	0	72
Hardwoods:													
Select white oaks	15	4	0	0	14	9	17	28	71	0	0	157	73
Select red oaks	22	0	0	0	38	24	52	61	29	0	0	0	54
Other red oaks	1	0	0	0	0	8	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	4	0	0	0	0	0	0	0	40	0	56	0	138
Soft maple	3	0	0	0	16	3	9	5	0	0	0	0	0
Ash	13	0	6	7	17	24	0	0	24	39	495	0	0
Balsam poplar	27	12	10	16	65	8	48	33	50	32	0	145	0
Paper birch	38	0	5	17	21	57	96	81	62	0	0	0	221
Bigtooth aspen	15	0	4	0	5	45	55	13	0	0	43	0	0
Quaking aspen	163	49	50	8	106	245	296	313	349	203	0	173	717
Basswood	16	0	6	0	8	0	36	4	71	0	0	0	493
Elm	5	0	0	0	0	15	6	13	10	0	0	0	76
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	322	66	81	48	290	439	615	550	705	274	595	475	1,772
Total all species	402	87	96	119	418	449	720	856	718	537	642	475	1,844
Number of plots	91	18	19	5	7	9	12	11	5	2	1	1	1
Standard error[3]	46	33	32	51	194	75	107	144	158	237	R	R	R
Average basal area	53	21	30	43	51	66	80	85	92	51	75	79	142

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 142.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Northern Pine Unit, Minnesota, 1977[1]

Aspen forest type - Site index class 51-60

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years) 0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	3	2	0	0	3	0	12	3	7	0	0	0	0
Red pine	9	4	3	4	8	9	14	6	44	0	0	0	0
Jack pine	33	14	30	27	38	46	57	14	37	0	0	0	0
White spruce	5	6	3	0	3	3	4	13	15	0	0	0	0
Black spruce	3	0	0	0	22	2	0	2	0	0	0	0	0
Balsam fir	19	6	16	5	38	10	30	44	0	0	0	0	0
Tamarack	1	0	1	0	3	0	4	0	0	0	0	0	0
Northern white-cedar	1	0	0	0	5	0	0	4	0	0	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	74	31	54	37	120	69	121	86	102	0	0	0	0
Hardwoods:													
Select white oaks	25	9	6	5	28	37	46	45	24	121	0	0	0
Select red oaks	21	10	3	5	15	40	24	25	46	313	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	2	2	0	0	3	3	5	0	0	0	0	0	0
Soft maple	4	2	0	0	0	0	8	14	11	73	0	0	0
Ash	13	2	5	3	21	20	4	39	37	0	0	0	0
Balsam poplar	31	11	21	0	73	17	57	32	53	0	0	0	0
Paper birch	47	21	14	42	28	22	98	99	96	0	0	0	0
Bigtooth aspen	24	1	2	3	0	39	29	35	182	0	0	0	0
Quaking aspen	279	70	123	130	314	422	462	404	421	441	0	0	0
Basswood	9	1	3	0	6	28	12	5	9	121	0	0	0
Elm	17	4	3	4	12	38	22	27	33	132	0	0	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	472	133	179	192	500	667	767	723	913	1,201	0	0	0
Total all species	546	165	233	228	619	736	888	809	1,015	1,201	0	0	0
Number of plots	252	43	44	21	27	35	42	25	13	2	0	0	0
Standard error	28	27	26	33	53	59	70	69	126	663	0	0	0
Average basal area	63	23	47	47	77	79	81	87	92	120	0	0	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

Table 143.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Northern Pine Unit, Minnesota, 1977[1]

Aspen forest type - Site index class 61-70

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)										
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	7	6	0	1	0	2	19	8	32	0	0	0	0
Red pine	19	12	9	6	5	18	20	37	116	0	0	0	0
Jack pine	21	10	14	26	33	17	31	7	6	165	0	0	0
White spruce	8	5	0	0	9	2	23	9	5	0	0	0	0
Black spruce	3	0	2	2	2	2	7	5	0	0	0	0	0
Balsam fir	29	8	5	11	18	27	48	52	59	113	0	0	0
Tamarack	3	0	0	2	0	6	6	0	0	0	0	0	0
Northern white-cedar	1	0	0	0	0	4	0	2	0	43	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	92	41	30	49	67	78	154	119	219	321	0	0	0
Hardwoods:													
Select white oaks	26	16	16	15	22	39	33	19	19	18	0	0	0
Select red oaks	39	11	10	10	33	41	53	79	72	42	128	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	9	2	5	1	7	10	8	19	6	37	111	0	0
Soft maple	6	3	2	3	2	7	14	3	8	9	0	0	0
Ash	13	6	3	15	9	18	16	21	14	6	0	0	0
Balsam poplar	33	11	13	21	42	39	36	44	81	29	35	0	0
Paper birch	84	35	16	55	70	106	127	117	62	41	0	0	0
Bigtooth aspen	32	1	1	0	11	40	66	48	54	0	0	0	0
Quaking aspen	477	106	157	230	492	636	599	692	656	663	1,205	0	0
Basswood	20	10	10	1	7	20	27	40	25	47	242	0	0
Elm	15	5	9	8	23	15	15	32	17	11	0	0	0
Select hardwoods	1	1	0	0	2	1	1	0	0	8	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	754	207	242	360	721	972	995	1,115	1,015	910	1,720	0	0
Total all species	846	247	271	408	788	1,049	1,149	1,234	1,233	1,231	1,720	0	0
Number of plots	530	68	51	41	53	125	116	55	14	5	2	0	0
Standard error	24	27	27	37	55	37	44	60	122	309	682	0	0
Average basal area	76	28	49	54	75	92	93	100	99	97	126	0	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

Table 144.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Northern Pine Unit, Minnesota, 1977[1]

Aspen forest type - Site index class 71-80

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)										
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	8	2	1	1	7	12	7	11	50	69	0	0	0
Red pine	24	16	4	9	10	30	37	46	0	159	0	0	0
Jack pine	25	11	10	54	24	29	18	12	114	105	0	0	0
White spruce	8	13	0	3	9	10	5	12	0	0	0	0	0
Black spruce	1	0	5	0	2	0	2	4	0	0	0	0	0
Balsam fir	49	6	20	8	42	62	55	135	152	110	0	0	0
Tamarack	4	0	0	3	7	4	5	0	0	0	0	0	0
Northern white-cedar	4	0	0	0	6	7	0	0	0	80	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	124	48	39	79	106	154	129	220	317	523	0	0	0
Hardwoods:													
Select white oaks	22	17	7	20	20	28	24	7	34	0	0	0	0
Select red oaks	39	16	13	22	31	48	56	45	191	11	0	0	0
Other red oaks	1	0	1	0	0	0	4	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	1	0	0	0	0	0	0
Hard maple	5	2	0	5	7	5	6	9	32	0	0	0	0
Soft maple	8	4	4	7	4	10	11	6	0	6	0	0	0
Ash	18	8	3	15	21	20	21	27	0	56	0	0	0
Balsam poplar	47	30	42	25	42	65	38	74	82	0	0	0	0
Paper birch	95	23	27	48	95	109	125	199	215	69	0	0	0
Bigtooth aspen	48	2	7	2	43	56	69	92	0	382	0	0	0
Quaking aspen	591	138	192	369	580	708	791	786	717	590	0	0	0
Basswood	21	0	18	15	17	28	26	11	20	7	0	0	0
Elm	15	2	9	11	10	19	26	17	0	0	0	0	0
Select hardwoods	0	0	0	0	0	0	1	0	0	0	0	0	0
Other hardwoods	0	0	0	0	2	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	912	241	322	539	871	1,096	1,198	1,275	1,291	1,120	0	0	0
Total all species	1,035	289	362	617	978	1,250	1,327	1,496	1,607	1,643	0	0	0
Number of plots	525	41	41	35	114	159	108	17	4	6	0	0	0
Standard error	25	32	36	56	42	39	47	137	247	279	0	0	0
Average basal area	84	31	53	70	83	95	101	102	108	110	0	0	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

Table 145.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Northern Pine Unit, Minnesota, 1977[1]

Aspen forest type - Site index class 81-90

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	8	0	0	5	11	5	9	40	0	0	111	0	0
Red pine	19	0	0	31	27	5	20	92	0	0	0	0	0
Jack pine	22	0	8	23	37	20	10	0	45	0	0	0	0
White spruce	6	0	0	6	6	5	8	27	0	0	0	0	0
Black spruce	5	45	0	3	2	0	11	0	0	0	0	0	0
Balsam fir	60	17	15	30	69	80	65	61	0	0	0	0	0
Tamarack	4	0	0	7	0	7	6	0	0	0	0	0	0
Northern white-cedar	2	0	0	0	6	1	0	0	0	0	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	126	62	23	105	159	123	129	220	45	0	111	0	0
Hardwoods:													
Select white oaks	20	11	10	30	19	14	35	24	25	0	0	0	0
Select red oaks	27	5	5	29	31	20	48	0	0	0	0	248	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	5	0	0	0	0	0	0	0	0	0	0
Hard maple	7	0	0	7	11	1	17	8	0	0	175	0	0
Soft maple	11	10	13	6	9	14	16	0	0	0	0	0	0
Ash	23	0	0	14	34	20	22	65	0	0	0	0	0
Balsam poplar	58	40	30	37	71	50	62	159	90	0	0	0	0
Paper birch	96	53	70	42	121	115	80	27	0	0	0	971	0
Bigtooth aspen	60	0	0	10	29	107	129	7	0	0	0	0	0
Quaking aspen	792	148	242	596	836	953	893	910	1,169	0	1,551	268	0
Basswood	23	6	62	20	13	22	29	63	0	0	229	0	0
Elm	18	5	5	11	22	19	30	7	0	0	0	0	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	1,136	279	443	801	1,196	1,335	1,361	1,270	1,284	0	1,955	1,487	0
Total all species	1,262	341	466	906	1,355	1,458	1,490	1,489	1,329	0	2,066	1,487	0
Number of plots	287	15	13	36	84	88	38	9	2	0	1	1	0
Standard error[3]	37	74	37	75	57	66	94	273	545	0	R	R	0
Average basal area	94	36	67	84	98	101	106	103	83	0	165	109	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 146.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Northern Pine Unit, Minnesota, 1977[1]

Aspen forest type - Site index class 91-100

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)										
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	12	0	0	20	2	10	16	111	0	0	0	0	0
Red pine	13	0	0	0	32	9	0	0	0	0	0	0	0
Jack pine	10	0	0	0	21	13	0	0	0	0	0	0	0
White spruce	44	0	0	0	21	76	109	305	0	0	0	0	0
Black spruce	9	0	0	39	0	0	0	0	0	0	0	0	0
Balsam fir	101	0	0	133	60	117	149	0	254	0	0	0	0
Tamarack	0	0	0	0	0	0	0	0	0	0	0	0	0
Northern white-cedar	5	0	0	0	0	0	42	0	0	0	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	194	0	0	192	136	225	316	416	254	0	0	0	0
Hardwoods:													
Select white oaks	36	0	31	66	20	25	13	292	0	0	0	0	0
Select red oaks	55	0	0	26	19	142	94	35	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	17	0	0	5	11	21	28	0	198	0	0	0	0
Soft maple	13	0	0	10	14	21	0	0	67	0	0	0	0
Ash	73	0	0	19	123	36	44	87	379	0	192	0	0
Balsam poplar	79	0	0	35	92	97	131	0	0	0	113	0	0
Paper birch	117	0	101	184	131	85	70	0	0	0	0	0	0
Bigtooth aspen	36	0	0	0	27	46	16	717	0	0	0	0	0
Quaking aspen	954	0	95	777	851	1,340	1,220	531	553	0	752	0	0
Basswood	30	0	0	26	34	39	27	0	0	0	34	0	0
Elm	44	0	0	6	61	32	110	0	0	0	62	0	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	1,456	0	228	1,154	1,382	1,885	1,753	1,661	1,196	0	1,154	0	0
Total all species	1,649	0	228	1,346	1,518	2,110	2,069	2,077	1,450	0	1,154	0	0
Number of plots	47	0	1	11	16	10	6	1	1	0	1	0	0
Standard error[3]	100	0	R	175	156	199	263	R	R	0	R	0	0
Average basal area	111	0	45	106	101	125	135	128	79	0	109	0	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 147.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Northern Pine Unit, Minnesota, 1977[1]

Aspen forest type - All site index classes

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	7	3	0	3	6	6	12	10	19	28	22	0	0
Red pine	19	9	4	12	16	18	24	44	58	64	0	0	0
Jack pine	24	11	16	29	30	24	27	12	29	97	0	0	0
White spruce	8	6	1	3	8	8	14	16	7	0	0	0	0
Black spruce	3	4	2	4	4	1	4	3	0	0	0	0	0
Balsam fir	41	7	12	24	46	51	53	66	43	106	9	0	72
Tamarack	3	0	0	3	3	5	5	0	0	6	0	0	0
Northern white-cedar	3	0	0	1	5	4	1	2	0	51	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	107	40	36	79	117	117	140	154	156	351	31	0	72
Hardwoods:													
Select white oaks	23	13	9	22	21	29	31	26	29	22	0	79	73
Select red oaks	34	10	7	18	29	41	50	55	64	60	51	124	54
Other red oaks	0	0	0	0	0	0	1	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	6	2	2	4	8	6	8	11	16	12	90	0	138
Soft maple	7	3	3	4	6	9	12	6	9	15	0	0	0
Ash	18	4	3	13	28	20	17	28	30	30	138	0	0
Balsam poplar	42	18	23	24	56	50	45	53	66	14	37	73	0
Paper birch	83	27	22	57	92	101	115	114	84	41	0	486	221
Bigtooth aspen	39	1	3	3	28	60	68	51	80	153	9	0	0
Quaking aspen	531	103	151	370	616	719	681	625	569	543	943	220	717
Basswood	19	5	13	11	14	24	25	27	23	34	149	0	493
Elm	16	4	6	8	18	20	23	25	19	21	12	0	76
Select hardwoods	0	0	0	0	0	0	0	0	0	3	0	0	0
Other hardwoods	0	0	0	0	1	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	820	189	242	533	916	1,078	1,076	1,019	988	948	1,429	981	1,772
Total all species	927	229	278	612	1,033	1,195	1,216	1,173	1,143	1,299	1,460	981	1,844
Number of plots	1,732	185	169	149	301	426	322	118	39	15	5	2	1
Standard error[3]	15	16	16	38	31	27	30	50	79	185	331	506	R
Average basal area	80	27	49	168	86	94	96	97	95	99	120	94	142

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 148.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Northern Pine Unit, Minnesota, 1977[1]

Paper birch forest type - Site index class 0-50

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years) 0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	13	0	0	0	0	0	31	19	0	0	0	0	0
Red pine	20	0	0	0	0	0	0	23	143	35	0	0	0
Jack pine	27	0	0	0	0	0	36	69	76	0	0	0	0
White spruce	16	0	0	0	0	0	28	0	42	26	0	0	0
Black spruce	11	0	0	79	0	0	16	27	0	0	0	0	0
Balsam fir	61	0	0	273	69	10	39	0	224	94	0	0	0
Tamarack	13	0	0	0	0	0	37	0	0	0	0	0	0
Northern white-cedar	26	0	0	0	111	0	0	0	0	215	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	186	0	0	352	180	10	186	137	485	370	0	0	0
Hardwoods:													
Select white oaks	9	0	0	0	0	32	0	42	0	0	0	0	0
Select red oaks	16	0	0	0	0	33	22	0	36	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	3	0	14	0	0	0	5	0	0	0	0	0	0
Soft maple	2	0	0	0	0	0	5	0	0	0	0	0	0
Ash	21	0	26	0	16	60	16	0	0	55	0	0	0
Balsam poplar	9	0	0	0	0	12	4	25	0	46	0	0	0
Paper birch	256	0	59	124	398	277	263	283	250	315	39	0	0
Bigtooth aspen	14	0	0	0	0	66	4	0	0	0	101	0	0
Quaking aspen	56	0	29	0	17	25	86	117	24	49	46	0	0
Basswood	8	0	0	0	0	22	0	8	38	0	0	0	0
Elm	19	0	0	0	0	21	6	3	18	41	258	0	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	413	0	129	124	431	549	411	478	366	506	444	0	0
Total all species	599	0	129	476	611	559	598	615	851	876	444	0	0
Number of plots	29	0	2	1	3	4	10	3	3	2	1	0	0
Standard error[3]	62	0	18	R	357	135	96	197	119	257	R	0	0
Average basal area	75	0	55	41	78	65	72	70	89	114	105	0	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 149.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Northern Pine Unit, Minnesota, 1977[1]

Paper birch forest type - Site index class 51-60

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)										
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:												
White pine	13	0	38	0	25	2	10	32	31	0	0	0	0
Red pine	43	0	30	0	0	38	47	13	371	0	92	0	0
Jack pine	22	0	0	31	0	55	9	27	0	0	0	0	0
White spruce	7	0	0	0	0	0	6	11	0	64	0	0	0
Black spruce	6	138	0	0	0	6	4	12	0	0	0	0	0
Balsam fir	75	0	0	19	54	61	30	128	0	316	472	65	0
Tamarack	5	0	30	0	13	0	10	0	0	0	0	0	0
Northern white-cedar	18	0	0	0	12	3	3	8	0	111	86	164	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	189	138	98	49	104	165	119	230	402	492	650	229	0
Hardwoods:												
Select white oaks	12	0	0	0	6	10	15	24	0	15	0	13	0
Select red oaks	43	0	0	0	0	74	41	63	58	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	2	0	0	0	0	0	0	11	0	0	0	0	0
Yellow birch	1	0	0	0	8	0	0	0	0	0	0	0	0
Hard maple	14	0	0	0	0	29	15	9	0	0	0	36	0
Soft maple	8	0	19	0	11	11	4	14	0	0	37	0	0
Ash	46	50	0	0	0	17	44	51	141	132	123	128	0
Balsam poplar	20	31	45	0	67	21	14	0	0	8	0	79	0
Paper birch	412	129	129	128	262	425	395	459	492	742	419	547	0
Bigtooth aspen	10	0	19	0	0	8	6	27	0	0	0	36	0
Quaking aspen	83	0	0	47	56	105	134	50	35	15	69	32	0
Basswood	30	0	0	0	0	14	31	52	0	48	149	107	0
Elm	21	0	0	0	0	24	1	34	100	46	0	54	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	702	209	212	176	409	740	701	794	827	1,005	797	1,032	0
Total all species	891	348	310	225	513	906	820	1,024	1,229	1,497	1,447	1,261	0
Number of plots	74	1	3	2	5	19	21	12	3	4	1	3	0
Standard error[3]	51	R	65	164	90	106	63	100	260	223	R	113	0
Average basal area	86	75	37	47	62	90	87	94	99	110	92	96	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 150.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Northern Pine Unit, Minnesota, 1977[1]

Paper birch forest type - Site index class 61-70

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	22	0	0	20	0	13	40	14	120	0	0	0	0
Red pine	47	0	0	0	79	17	89	65	0	0	0	0	0
Jack pine	20	0	0	0	88	6	11	27	22	0	0	0	0
White spruce	9	32	0	0	0	8	9	16	18	0	0	0	0
Black spruce	1	0	0	0	0	3	0	0	0	0	0	0	0
Balsam fir	44	0	0	0	5	36	37	76	59	342	0	0	0
Tamarack	4	0	0	0	32	0	0	0	0	0	0	0	0
Northern white-cedar	13	0	0	0	0	7	15	8	0	281	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	159	32	0	20	204	90	200	206	219	623	0	0	0
Hardwoods:													
Select white oaks	16	0	46	9	12	9	20	23	11	45	0	0	0
Select red oaks	81	0	0	109	86	70	99	105	49	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	3	0	0	0	0	1	0	0	54	0	0	0	0
Hard maple	11	0	0	0	3	16	1	26	0	0	0	0	0
Soft maple	12	0	0	0	8	19	11	10	6	0	0	0	0
Ash	22	0	0	57	28	22	2	38	0	103	0	0	0
Balsam poplar	27	0	0	48	13	51	13	16	18	0	0	0	0
Paper birch	525	36	285	315	464	514	529	659	736	618	0	0	0
Bigtooth aspen	30	0	0	0	41	39	36	14	38	0	0	0	0
Quaking aspen	126	0	76	129	106	105	161	115	203	309	0	0	0
Basswood	29	0	0	0	17	27	40	43	0	32	0	0	0
Elm	32	0	0	0	18	50	18	43	7	54	0	0	0
Select hardwoods	1	0	0	0	0	0	2	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	914	36	406	667	793	922	932	1,092	1,122	1,162	0	0	0
Total all species	1,073	69	406	688	997	1,012	1,133	1,298	1,342	1,785	0	0	0
Number of plots	98	2	2	4	11	33	23	17	4	2	0	0	0
Standard error	52	69	255	189	137	68	99	145	313	383	0	0	0
Average basal area	92	17	45	101	91	92	94	96	102	122	0	0	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

Table 151.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Northern Pine Unit, Minnesota, 1977[1]

Paper birch forest type - Site index class 71-80

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years) 0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	19	0	0	0	0	19	11	94	0	0	0	0	0
Red pine	40	0	0	0	18	43	18	177	0	0	0	0	0
Jack pine	36	0	0	0	0	0	141	0	0	0	0	0	0
White spruce	17	0	0	0	0	19	41	0	0	0	0	0	0
Black spruce	0	0	0	0	0	0	0	0	0	0	0	0	0
Balsam fir	118	0	0	0	177	32	262	29	123	0	131	0	0
Tamarack	3	0	0	82	0	0	0	0	0	0	0	0	0
Northern white-cedar	9	0	0	0	0	0	0	0	0	0	285	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	242	0	0	82	195	113	472	300	123	0	416	0	0
Hardwoods:													
Select white oaks	28	0	0	0	17	23	39	50	75	0	0	0	0
Select red oaks	56	0	0	0	62	128	0	0	0	0	0	0	0
Other red oaks	2	0	0	0	0	4	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	13	0	0	0	0	23	0	0	147	0	0	0	0
Soft maple	28	0	0	0	0	34	58	12	0	0	0	0	0
Ash	33	0	0	0	0	9	59	0	0	0	464	0	0
Balsam poplar	97	0	0	281	177	39	55	124	0	0	614	0	0
Paper birch	554	0	475	0	399	661	549	609	749	0	456	0	0
Bigtooth aspen	18	0	0	0	66	21	0	0	0	0	0	0	0
Quaking aspen	135	0	0	70	251	142	125	100	0	0	0	0	0
Basswood	24	0	0	0	0	43	13	0	155	0	0	0	0
Elm	15	0	0	0	0	2	30	42	0	0	83	0	0
Select hardwoods	2	0	0	0	0	6	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	1,005	0	475	351	972	1,135	927	938	1,126	0	1,617	0	0
Total all species	1,247	0	475	433	1,166	1,248	1,400	1,237	1,249	0	2,033	0	0
Number of plots	31	0	1	1	5	11	8	3	1	0	1	0	0
Standard error[3]	89	0	R	R	170	95	244	259	R	0	R	0	0
Average basal area	99	0	60	41	103	109	100	76	98	0	128	0	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 152.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Northern Pine Unit, Minnesota, 1977[1]

Paper birch forest type - All site index classes

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)										
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:												
White pine	19	0	14	10	4	10	25	42	52	0	0	0	0
Red pine	43	0	11	0	32	39	51	52	140	9	31	0	0
Jack pine	23	0	0	8	32	19	31	28	29	0	0	0	0
White spruce	10	16	0	0	0	7	15	11	18	39	0	0	0
Black spruce	4	35	0	10	0	3	4	6	0	0	0	0	0
Balsam fir	67	0	0	39	78	40	64	81	94	267	201	65	0
Tamarack	5	0	11	10	14	0	9	0	0	0	0	0	0
Northern white-cedar	15	0	0	0	15	4	7	6	0	179	124	164	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	186	51	37	77	175	122	206	226	333	494	355	229	0
Hardwoods:												
Select white oaks	16	0	11	5	19	13	17	26	11	19	0	13	0
Select red oaks	56	0	0	54	42	77	54	73	44	0	0	0	0
Other red oaks	0	0	0	0	0	1	0	0	0	0	0	0	0
Hickory	1	0	0	0	0	0	0	4	0	0	0	0	0
Yellow birch	1	0	0	0	1	1	0	0	20	0	0	0	0
Hard maple	12	0	4	0	7	20	6	15	13	0	0	36	0
Soft maple	12	8	7	0	5	20	14	10	2	0	12	0	0
Ash	32	13	7	29	26	21	26	35	39	106	195	128	0
Balsam poplar	33	8	17	59	64	37	17	20	7	15	205	79	0
Paper birch	466	92	194	205	451	506	443	553	538	604	305	547	0
Bigtooth aspen	21	0	7	0	35	29	16	15	14	0	34	36	0
Quaking aspen	107	0	26	85	121	113	135	89	90	97	38	32	0
Basswood	27	0	0	0	22	27	27	38	25	32	50	107	0
Elm	25	0	0	0	15	33	12	35	35	47	114	54	0
Select hardwoods	0	0	0	0	0	1	1	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	807	120	273	437	806	898	769	915	836	920	953	1,032	0
Total all species	994	171	309	514	981	1,020	975	1,141	1,169	1,414	1,308	1,261	0
Number of plots	241	4	8	8	30	68	62	36	11	8	3	3	0
Standard error	33	72	69	118	91	57	62	85	138	184	464	113	0
Average basal area	89	34	46	73	88	93	89	91	97	114	108	96	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

Table 153.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Northern Pine Unit, Minnesota, 1977[1]

Balsam poplar forest type - Site index class 0-50

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	1	0	0	0	0	0	0	0	20	0	0	0	0
Red pine	0	0	0	0	0	0	0	0	0	0	0	0	0
Jack pine	11	0	0	0	0	109	0	0	0	0	0	0	0
White spruce	3	0	0	0	8	14	0	0	0	0	0	0	0
Black spruce	1	0	0	0	5	0	0	0	0	0	0	0	0
Balsam fir	5	0	4	0	0	29	0	15	0	0	0	0	0
Tamarack	0	0	0	0	0	0	0	0	0	0	0	0	0
Northern white-cedar	0	0	0	0	0	0	0	0	0	0	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	22	0	4	0	13	153	0	15	20	0	0	0	0
Hardwoods:													
Select white oaks	1	0	4	0	0	0	0	0	7	0	0	0	0
Select red oaks	1	0	0	0	0	0	0	0	23	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Soft maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	16	0	7	0	4	11	0	20	181	0	0	0	0
Balsam poplar	196	189	71	91	136	369	255	391	595	0	0	0	0
Paper birch	18	0	0	8	20	0	0	0	183	0	0	0	0
Bigtooth aspen	0	0	0	0	0	0	0	0	0	0	0	0	0
Quaking aspen	82	41	69	73	77	121	228	162	0	0	0	0	0
Basswood	10	0	0	0	0	91	0	0	0	0	0	0	0
Elm	6	0	0	0	14	8	0	5	18	0	0	0	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	330	230	151	172	250	600	484	578	1,007	0	0	0	0
Total all species	352	230	155	172	263	753	484	593	1,027	0	0	0	0
Number of plots	48	6	10	7	12	5	2	3	3	0	0	0	0
Standard error	46	106	51	39	42	151	61	109	193	0	0	0	0
Average basal area	51	28	44	40	49	81	53	60	101	0	0	0	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

Table 154.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Northern Pine Unit, Minnesota, 1977[1]

Balsam poplar forest type - Site index class 51-60

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years) 0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	0	0	0	0	0	0	0	0	0	0	0	0	0
Red pine	0	0	0	0	0	0	0	0	0	0	0	0	0
Jack pine	2	0	0	0	0	0	0	26	0	0	0	0	0
White spruce	5	0	0	0	0	0	24	15	0	0	0	0	0
Black spruce	4	0	0	0	0	0	30	0	0	0	0	0	0
Balsam fir	25	15	13	0	0	0	25	158	39	0	0	0	0
Tamarack	7	0	11	0	0	0	0	0	60	0	0	0	0
Northern white-cedar	3	0	0	0	0	0	18	0	10	0	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	47	15	23	0	0	0	98	199	109	0	0	0	0
Hardwoods:													
Select white oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Select red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Soft maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	35	7	0	0	0	43	59	107	115	0	0	0	0
Balsam poplar	305	114	63	375	252	462	665	366	379	0	0	0	0
Paper birch	13	0	0	17	0	7	71	16	0	0	0	0	0
Bigtooth aspen	0	0	0	0	0	0	0	0	0	0	0	0	0
Quaking aspen	72	35	29	60	169	90	140	27	44	0	0	0	0
Basswood	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	14	30	11	0	0	7	7	14	40	0	0	0	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	438	186	103	452	421	610	941	530	578	0	0	0	0
Total all species	485	201	127	452	421	610	1,039	730	686	0	0	0	0
Number of plots	46	7	10	3	5	7	6	4	4	0	0	0	0
Standard error	64	80	29	177	103	107	252	253	163	0	0	0	0
Average basal area	56	32	37	77	56	65	85	65	56	0	0	0	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

Table 155.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Northern Pine Unit, Minnesota, 1977[1]

Balsam poplar forest type - Site index class 61-70

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	1	0	0	0	0	6	0	0	0	0	0	0	0
Red pine	0	0	0	0	0	0	0	0	0	0	0	0	0
Jack pine	0	0	0	0	0	0	0	0	0	0	0	0	0
White spruce	8	0	0	0	0	8	20	8	55	0	0	0	0
Black spruce	5	0	0	0	0	23	0	0	0	0	0	0	0
Balsam fir	50	0	0	0	19	93	84	82	104	0	0	0	0
Tamarack	38	0	19	0	0	48	66	120	0	0	0	0	0
Northern white-cedar	13	0	0	0	30	6	0	72	22	0	0	0	0
Other softwoods	1	0	0	0	0	7	0	0	0	0	0	0	0
Total	116	0	19	0	49	190	170	282	181	0	0	0	0
Hardwoods:													
Select white oaks	5	0	13	0	0	0	9	0	38	0	0	0	0
Select red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	1	0	0	0	0	0	0	9	0	0	0	0	0
Soft maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	26	0	11	0	0	24	24	94	169	0	0	0	0
Balsam poplar	366	17	145	198	377	556	438	612	405	0	0	0	0
Paper birch	47	0	16	0	64	51	30	179	72	0	0	0	0
Bigtooth aspen	0	0	0	0	0	0	0	0	0	0	0	0	0
Quaking aspen	107	58	50	70	183	102	138	147	39	0	0	0	0
Basswood	4	0	0	0	0	0	22	0	0	0	0	0	0
Elm	22	0	14	0	34	23	22	35	101	0	0	0	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	578	75	249	267	658	756	683	1,076	824	0	0	0	0
Total all species	695	75	267	267	707	947	853	1,357	1,005	0	0	0	0
Number of plots	63	6	10	5	8	14	12	6	2	0	0	0	0
Standard error	61	36	83	68	49	119	94	169	206	0	0	0	0
Average basal area	64	13	38	50	68	85	67	100	87	0	0	0	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

Table 156.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Northern Pine Unit, Minnesota, 1977[1]

Balsam poplar forest type - Site index class 71-80

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)										
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	3	0	0	0	0	0	22	0	0	0	0	0	0
Red pine	5	0	0	0	0	0	39	0	0	0	0	0	0
Jack pine	4	0	0	0	0	0	33	0	0	0	0	0	0
White spruce	8	30	0	0	12	0	0	0	0	79	0	0	0
Black spruce	0	0	0	0	0	0	0	0	0	0	0	0	0
Balsam fir	80	15	0	79	174	32	225	50	0	163	0	0	0
Tamarack	1	0	0	0	6	0	0	0	0	0	0	0	0
Northern white-cedar	20	0	0	0	0	0	0	0	0	858	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	120	45	0	79	192	32	319	50	0	1,100	0	0	0
Hardwoods:													
Select white oaks	14	0	5	70	0	0	40	0	0	0	0	0	0
Select red oaks	5	0	0	0	11	8	10	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	12	0	0	0	49	0	23	19	0	0	0	0	0
Soft maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	35	26	7	45	0	71	18	74	0	194	0	0	0
Balsam poplar	557	136	126	523	514	1,003	625	1,256	0	849	0	0	0
Paper birch	50	0	21	52	94	42	88	0	0	216	0	0	0
Bigtooth aspen	0	0	0	0	0	0	0	0	0	0	0	0	0
Quaking aspen	144	0	53	127	166	213	314	165	0	0	0	0	0
Basswood	11	0	0	12	27	0	27	30	0	0	0	0	0
Elm	47	0	60	11	9	65	52	274	0	0	0	0	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	876	162	271	840	870	1,403	1,199	1,818	0	1,259	0	0	0
Total all species	996	207	271	919	1,062	1,435	1,518	1,868	0	2,360	0	0	0
Number of plots	42	5	8	5	7	9	5	2	0	1	0	0	0
Standard error[3]	108	113	82	137	105	224	234	311	0	R	0	0	0
Average basal area	74	19	39	90	81	93	95	105	0	165	0	0	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 157.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Northern Pine Unit, Minnesota, 1977[1]

Balsam poplar forest type - Site index class 81-90

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years) 0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	0	0	0	0	0	0	0	0	0	0	0	0	0
Red pine	0	0	0	0	0	0	0	0	0	0	0	0	0
Jack pine	0	0	0	0	0	0	0	0	0	0	0	0	0
White spruce	0	0	0	0	0	0	0	0	0	0	0	0	0
Black spruce	0	0	0	0	0	0	0	0	0	0	0	0	0
Balsam fir	254	0	0	0	129	332	350	0	0	0	0	0	0
Tamarack	0	0	0	0	0	0	0	0	0	0	0	0	0
Northern white-cedar	4	0	0	0	0	0	18	0	0	0	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	258	0	0	0	129	332	368	0	0	0	0	0	0
Hardwoods:													
Select white oaks	4	0	0	0	0	0	0	48	0	0	0	0	0
Select red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Soft maple	5	0	0	0	0	11	0	0	0	0	0	0	0
Ash	109	0	0	0	0	148	178	0	0	0	0	0	0
Balsam poplar	712	0	0	0	589	622	1,081	1,110	0	0	0	0	0
Paper birch	87	0	0	0	157	80	114	0	0	0	0	0	0
Bigtooth aspen	6	0	0	0	0	0	28	0	0	0	0	0	0
Quaking aspen	226	0	0	0	156	296	54	688	0	0	0	0	0
Basswood	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	32	0	0	0	0	49	40	0	0	0	0	0	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	1,183	0	0	0	902	1,206	1,495	1,846	0	0	0	0	0
Total all species	1,440	0	0	0	1,031	1,538	1,863	1,846	0	0	0	0	0
Number of plots	13	1	0	0	2	6	3	1	0	0	0	0	0
Standard error[3]	169	R	0	0	174	177	209	R	0	0	0	0	0
Average basal area	88	4	0	0	83	97	93	112	0	0	0	0	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 158.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Northern Pine Unit, Minnesota, 1977[1]

Balsam poplar forest type - All site index classes

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	1	0	0	0	0	2	4	0	7	0	0	0	0
Red pine	1	0	0	0	0	0	7	0	0	0	0	0	0
Jack pine	4	0	0	0	0	13	6	7	0	0	0	0	0
White spruce	6	6	0	0	5	4	14	7	12	79	0	0	0
Black spruce	3	0	0	0	2	8	7	0	0	0	0	0	0
Balsam fir	53	7	4	19	48	91	119	79	40	163	0	0	0
Tamarack	13	0	8	0	1	16	28	45	27	0	0	0	0
Northern white-cedar	9	0	0	0	7	2	6	27	10	858	0	0	0
Other softwoods	0	0	0	0	0	2	0	0	0	0	0	0	0
Total	89	13	12	19	63	139	190	164	95	1,100	0	0	0
Hardwoods:													
Select white oaks	5	0	5	17	0	0	11	3	11	0	0	0	0
Select red oaks	1	0	0	0	2	2	2	0	8	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	3	0	0	0	10	0	4	6	0	0	0	0	0
Soft maple	0	0	0	0	0	2	0	0	0	0	0	0	0
Ash	33	7	6	14	1	54	45	75	149	194	0	0	0
Balsam poplar	373	109	100	269	314	625	576	621	457	849	0	0	0
Paper birch	37	0	8	27	51	39	56	71	77	216	0	0	0
Bigtooth aspen	0	0	0	0	0	0	3	0	0	0	0	0	0
Quaking aspen	109	34	50	89	139	155	167	156	28	0	0	0	0
Basswood	6	0	0	3	6	11	14	4	0	0	0	0	0
Elm	23	9	19	6	15	32	24	52	46	0	0	0	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	589	158	189	425	537	920	903	987	775	1,259	0	0	0
Total all species	678	171	202	444	600	1,059	1,093	1,151	871	2,360	0	0	0
Number of plots	213	25	38	21	34	41	28	16	9	1	0	0	0
Standard error[3]	40	41	32	80	64	88	106	149	110	R	0	0	0
Average basal area	63	23	40	61	63	85	78	85	78	165	0	0	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 159.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Central Hardwood Unit, Minnesota, 1977[1]

Black spruce forest type - Site index class 0-50

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	6	0	0	9	0	0	0	34	0	0	0	0	0
Red pine	0	0	0	0	0	0	0	0	0	0	0	0	0
Jack pine	0	0	0	0	0	0	0	0	0	0	0	0	0
White spruce	0	0	0	0	0	0	0	0	0	0	0	0	0
Black spruce	104	0	43	50	137	117	139	236	0	0	0	0	0
Balsam fir	12	0	0	13	0	0	9	63	0	0	0	0	0
Tamarack	70	0	0	64	0	18	146	40	0	0	0	0	0
Northern white-cedar	0	0	0	0	0	0	0	0	0	0	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	191	0	43	135	137	134	294	373	0	0	0	0	0
Hardwoods:													
Select white oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Select red oaks	3	0	0	9	0	0	0	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Soft maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	3	0	0	9	0	0	0	0	0	0	0	0	0
Balsam poplar	0	0	0	0	0	0	0	0	0	0	0	0	0
Paper birch	19	0	0	0	0	0	67	0	0	0	0	0	0
Bigtooth aspen	3	0	0	0	0	0	0	37	0	0	0	0	0
Quaking aspen	34	0	0	82	0	0	10	33	0	0	0	0	0
Basswood	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	0	0	0	0	0	0	0	0	0	0	0	0	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	62	0	0	100	0	0	77	70	0	0	0	0	0
Total all species	253	0	43	235	137	134	370	443	0	0	0	0	0
Number of plots	14	0	1	5	1	2	4	1	0	0	0	0	0
Standard error[3]	51	0	R	90	R	R	107	R	0	0	0	0	0
Average basal area	62	0	19	62	71	68	56	109	0	0	0	0	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 160.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Central Hardwood Unit, Minnesota, 1977[1]

Black spruce forest type - All site index classes

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years) 0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	6	0	0	9	0	0	0	34	0	0	0	0	0
Red pine	0	0	0	0	0	0	0	0	0	0	0	0	0
Jack pine	0	0	0	0	0	0	0	0	0	0	0	0	0
White spruce	0	0	0	0	0	0	0	0	0	0	0	0	0
Black spruce	104	0	43	50	137	117	139	236	0	0	0	0	0
Balsam fir	12	0	0	13	0	0	9	63	0	0	0	0	0
Tamarack	70	0	0	64	0	18	146	40	0	0	0	0	0
Northern white-cedar	0	0	0	0	0	0	0	0	0	0	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	191	0	43	135	137	134	294	373	0	0	0	0	0
Hardwoods:													
Select white oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Select red oaks	3	0	0	9	0	0	0	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Soft maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	3	0	0	9	0	0	0	0	0	0	0	0	0
Balsam poplar	0	0	0	0	0	0	0	0	0	0	0	0	0
Paper birch	19	0	0	0	0	0	67	0	0	0	0	0	0
Bigtooth aspen	3	0	0	0	0	0	0	37	0	0	0	0	0
Quaking aspen	34	0	0	82	0	0	10	33	0	0	0	0	0
Basswood	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	0	0	0	0	0	0	0	0	0	0	0	0	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	62	0	0	100	0	0	77	70	0	0	0	0	0
Total all species	253	0	43	235	137	134	370	443	0	0	0	0	0
Number of plots	14	0	1	5	1	2	4	1	0	0	0	0	0
Standard error[3]	51	0	R	90	R	R	107	R	0	0	0	0	0
Average basal area	62	0	19	62	71	68	56	109	0	0	0	0	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 161.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Central Hardwood Unit, Minnesota, 1977[1]

Tamarack forest type - Site index class 0-50

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	9	0	47	0	0	0	0	0	0	0	0	0	0
Red pine	0	0	0	0	0	0	0	0	0	0	0	0	0
Jack pine	0	0	0	0	0	0	0	0	0	0	0	0	0
White spruce	3	0	0	38	0	0	0	0	0	0	0	0	0
Black spruce	19	0	23	0	0	12	0	169	0	0	0	0	0
Balsam fir	0	0	0	0	0	0	0	0	0	0	0	0	0
Tamarack	443	0	162	106	0	485	744	183	258	563	0	826	981
Northern white-cedar	0	0	0	0	0	0	0	0	0	0	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	475	0	233	144	0	497	744	353	258	563	0	826	981
Hardwoods:													
Select white oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Select red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Soft maple	4	0	0	0	0	0	0	0	0	29	0	0	0
Ash	2	0	0	0	0	7	0	0	0	0	0	0	0
Balsam poplar	6	0	0	0	0	0	0	0	0	45	0	0	0
Paper birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Bigtooth aspen	0	0	0	0	0	0	0	0	0	0	0	0	0
Quaking aspen	7	0	0	0	0	16	0	39	0	0	0	0	0
Basswood	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	15	0	0	0	0	25	0	0	0	22	0	86	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	34	0	0	0	0	48	0	39	0	96	0	86	0
Total all species	509	0	233	144	0	545	744	392	258	660	0	911	981
Number of plots	15	0	3	1	0	4	1	1	1	2	0	1	1
Standard error[3]	73	0	93	R	0	92	R	R	R	160	0	R	R
Average basal area	58	0	45	49	0	67	68	64	19	58	0	56	94

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[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 160.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Central Hardwood Unit, Minnesota, 1977[1]

Black spruce forest type - All site index classes

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years) 0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	6	0	0	9	0	0	0	34	0	0	0	0	0
Red pine	0	0	0	0	0	0	0	0	0	0	0	0	0
Jack pine	0	0	0	0	0	0	0	0	0	0	0	0	0
White spruce	0	0	0	0	0	0	0	0	0	0	0	0	0
Black spruce	104	0	43	50	137	117	139	236	0	0	0	0	0
Balsam fir	12	0	0	13	0	0	9	63	0	0	0	0	0
Tamarack	70	0	0	64	0	18	146	40	0	0	0	0	0
Northern white-cedar	0	0	0	0	0	0	0	0	0	0	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	191	0	43	135	137	134	294	373	0	0	0	0	0
Hardwoods:													
Select white oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Select red oaks	3	0	0	9	0	0	0	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Soft maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	3	0	0	9	0	0	0	0	0	0	0	0	0
Balsam poplar	0	0	0	0	0	0	0	0	0	0	0	0	0
Paper birch	19	0	0	0	0	0	67	0	0	0	0	0	0
Bigtooth aspen	3	0	0	0	0	0	0	37	0	0	0	0	0
Quaking aspen	34	0	0	82	0	0	10	33	0	0	0	0	0
Basswood	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	0	0	0	0	0	0	0	0	0	0	0	0	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	62	0	0	100	0	0	77	70	0	0	0	0	0
Total all species	253	0	43	235	137	134	370	443	0	0	0	0	0
Number of plots	14	0	1	5	1	2	4	1	0	0	0	0	0
Standard error[3]	51	0	R	90	R	R	107	R	0	0	0	0	0
Average basal area	62	0	19	62	71	68	56	109	0	0	0	0	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 161.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Central Hardwood Unit, Minnesota, 1977[1]

Tamarack forest type - Site index class 0-50

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	9	0	47	0	0	0	0	0	0	0	0	0	0
Red pine	0	0	0	0	0	0	0	0	0	0	0	0	0
Jack pine	0	0	0	0	0	0	0	0	0	0	0	0	0
White spruce	3	0	0	38	0	0	0	0	0	0	0	0	0
Black spruce	19	0	23	0	0	12	0	169	0	0	0	0	0
Balsam fir	0	0	0	0	0	0	0	0	0	0	0	0	0
Tamarack	443	0	162	106	0	485	744	183	258	563	0	826	981
Northern white-cedar	0	0	0	0	0	0	0	0	0	0	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	475	0	233	144	0	497	744	353	258	563	0	826	981
Hardwoods:													
Select white oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Select red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Soft maple	4	0	0	0	0	0	0	0	0	29	0	0	0
Ash	2	0	0	0	0	7	0	0	0	0	0	0	0
Balsam poplar	6	0	0	0	0	0	0	0	0	45	0	0	0
Paper birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Bigtooth aspen	0	0	0	0	0	0	0	0	0	0	0	0	0
Ouaking aspen	7	0	0	0	0	16	0	39	0	0	0	0	0
Basswood	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	15	0	0	0	0	25	0	0	0	22	0	86	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	34	0	0	0	0	48	0	39	0	96	0	86	0
Total all species	509	0	233	144	0	545	744	392	258	660	0	911	981
Number of plots	15	0	3	1	0	4	1	1	1	2	0	1	1
Standard error[3]	73	0	93	R	0	92	R	R	R	160	0	R	R
Average basal area	58	0	45	49	0	67	68	64	19	58	0	56	94

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 162.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Central Hardwood Unit, Minnesota, 1977[1]

Tamarack forest type - All site index classes

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)										
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	6	0	35	0	0	0	0	0	0	0	0	0	0
Red pine	0	0	0	0	0	0	0	0	0	0	0	0	0
Jack pine	0	0	0	0	0	0	0	0	0	0	0	0	0
White spruce	2	0	0	19	0	0	0	0	0	0	0	0	0
Black spruce	15	0	18	0	60	10	0	85	0	0	0	0	0
Balsam fir	2	0	14	0	0	0	0	0	0	0	0	0	0
Tamarack	503	0	176	145	294	632	807	443	258	563	618	826	981
Northern white-cedar	0	0	0	0	0	0	0	0	0	0	0	0	0
Cther softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	528	0	243	164	354	642	807	528	258	563	618	826	981
Hardwoods:													
Select white oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Select red oaks	3	0	0	0	0	15	0	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Soft maple	3	0	0	0	0	0	0	0	0	29	0	0	0
Ash	1	0	0	0	0	6	0	0	0	0	0	0	0
Balsam poplar	4	0	0	0	0	0	0	0	0	45	0	0	0
Paper birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Bigtooth aspen	0	0	0	0	0	0	0	0	0	0	0	0	0
Ouaking aspen	10	0	31	0	0	12	0	20	0	0	0	0	0
Basswood	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	13	0	0	0	0	32	0	0	0	22	0	86	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	33	0	31	0	0	65	0	20	0	96	0	86	0
Total all species	562	0	274	164	354	707	807	548	258	660	618	911	981
Number of plots	23	0	4	2	1	5	3	2	1	2	1	1	1
Standard error[3]	68	0	77	21	R	176	156	156	R	160	R	R	R
Average basal area	55	0	45	34	49	73	63	49	19	58	41	56	94

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 163.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Central Hardwood Unit, Minnesota 1977[1]

Oak-hickory forest type - Site index class 0-50

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years) 0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	1	0	3	0	0	0	0	0	7	0	0	0	0
Red pine	5	0	11	0	0	0	0	0	3	20	0	2	0
Jack pine	0	0	0	0	0	0	0	0	0	0	0	0	0
White spruce	0	0	0	0	0	6	0	0	0	0	0	0	0
Black spruce	0	0	0	0	0	0	0	0	0	0	0	0	0
Balsam fir	0	0	0	0	0	0	0	0	0	0	0	0	0
Tamarack	0	0	0	0	0	0	0	0	0	0	0	0	0
Northern white-cedar	0	0	0	0	0	0	0	0	0	0	0	0	0
Other softwoods	4	0	0	0	26	0	3	17	2	2	2	0	0
Total	10	0	14	0	26	6	3	17	12	22	2	2	0
Hardwoods:													
Select white oaks	237	51	82	18	111	123	170	270	187	341	246	308	255
Select red oaks	283	44	124	0	335	233	300	220	392	308	272	327	361
Other red oaks	13	0	0	0	0	0	0	4	6	16	41	11	0
Hickory	11	0	0	30	0	0	21	8	4	6	21	25	9
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	6	0	5	0	0	0	0	9	5	0	7	25	0
Soft maple	1	0	0	0	0	7	0	2	2	0	4	0	0
Ash	10	0	0	0	0	4	23	6	20	12	10	2	0
Balsam poplar	0	0	0	0	0	0	0	0	0	0	3	0	0
Paper birch	23	18	9	68	30	46	38	36	20	14	20	27	0
Bigtooth aspen	4	0	6	0	0	0	4	3	10	3	5	0	0
Quaking aspen	24	13	8	0	137	0	17	36	33	17	24	19	0
Basswood	23	0	0	0	0	50	20	26	14	10	35	46	29
Elm	44	25	17	39	24	27	16	44	45	56	51	52	37
Select hardwoods	11	0	0	0	14	0	12	6	7	18	13	18	6
Other hardwoods	3	0	0	0	0	0	0	9	5	0	2	4	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	694	152	250	154	652	489	621	679	751	800	753	863	698
Total all species	704	152	264	154	678	495	624	696	763	822	755	864	698
Number of plots	179	5	9	2	3	6	11	25	27	32	34	20	5
Standard error	29	58	18	40	165	120	70	66	64	83	52	118	113
Average basal area	80	40	52	30	78	64	73	82	92	83	83	89	86

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

Table 164.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Central Hardwood Unit, Minnesota, 1977[1]

Oak-hickory forest type - Site index class 51-60

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	0	0	0	0	0	0	0	0	0	0	0	0	0
Red pine	0	0	0	0	0	0	0	0	0	0	0	0	0
Jack pine	0	0	0	0	0	0	3	0	0	0	0	0	0
White spruce	0	0	0	0	0	0	0	0	0	0	0	0	0
Black spruce	0	0	0	0	0	0	0	0	0	0	0	0	0
Balsam fir	0	0	0	0	0	0	0	0	0	0	0	0	0
Tamarack	0	0	0	0	0	0	0	0	0	0	0	0	0
Northern white-cedar	0	0	0	0	0	0	0	0	0	0	0	0	0
Other softwoods	3	0	0	0	0	0	0	10	3	0	0	0	0
Total	3	0	0	0	0	0	3	10	3	0	0	0	0
Hardwoods:													
Select white oaks	193	0	133	0	310	121	274	204	115	252	160	249	0
Select red oaks	527	329	127	0	284	395	324	567	650	611	926	682	0
Other red oaks	13	78	0	0	0	6	7	19	40	0	6	0	0
Hickory	20	0	45	0	27	56	11	23	0	0	15	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	8	0	0	0	0	2	4	7	3	38	11	16	0
Soft maple	8	0	0	0	0	6	14	0	11	9	0	34	0
Ash	12	0	0	0	46	9	17	15	10	0	10	0	0
Balsam poplar	3	0	0	0	0	0	0	0	15	7	0	0	0
Paper birch	49	0	0	0	54	45	81	43	43	66	40	24	0
Bigtooth aspen	12	0	0	0	0	26	7	21	5	16	0	0	0
Quaking aspen	47	0	0	0	71	115	54	23	74	0	12	0	0
Basswood	29	61	0	0	10	18	41	11	33	47	41	70	0
Elm	46	0	0	0	37	37	21	61	42	58	79	56	0
Select hardwoods	12	0	0	0	0	9	6	20	6	30	17	4	0
Other hardwoods	9	0	0	0	0	4	2	13	10	41	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	987	468	305	0	838	850	862	1,025	1,058	1,176	1,317	1,137	0
Total all species	990	468	305	0	838	850	864	1,035	1,061	1,176	1,317	1,137	0
Number of plots	110	1	3	0	4	19	18	25	14	9	10	7	0
Standard error[3]	41	R	44	0	258	88	85	78	116	130	145	153	0
Average basal area	89	38	59	0	91	88	83	88	94	89	106	91	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 165.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Central Hardwood Unit, Minnesota, 1977[1]

Oak-hickory forest type - Site index class 61-70

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years) 0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	1	0	0	0	0	3	0	0	0	0	0	0	0
Red pine	3	0	0	0	0	12	0	0	0	0	0	0	0
Jack pine	0	0	0	0	0	0	0	0	0	0	0	0	0
White spruce	0	0	0	0	0	0	0	0	0	0	0	0	0
Black spruce	0	0	0	0	0	0	0	0	0	0	0	0	0
Balsam fir	0	0	0	0	0	0	0	0	0	0	0	0	0
Tamarack	0	0	0	0	0	0	0	0	0	0	0	0	0
Northern white-cedar	0	0	0	0	0	0	0	0	0	0	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	4	0	0	0	0	15	0	0	0	0	0	0	0
Hardwoods:													
Select white oaks	175	0	0	96	42	182	197	165	143	87	593	0	0
Select red oaks	571	0	212	170	480	456	743	576	675	678	613	0	0
Other red oaks	8	0	0	0	0	0	32	0	0	0	0	0	0
Hickory	42	0	0	0	94	2	34	117	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	9	0	0	0	0	15	7	15	0	0	0	0	0
Soft maple	6	0	0	0	0	18	5	0	0	0	0	0	0
Ash	10	0	0	0	0	15	12	3	37	0	12	0	0
Balsam poplar	1	0	0	0	0	3	0	0	0	0	0	0	0
Paper birch	69	0	0	34	53	91	79	90	0	0	23	0	0
Bigtooth aspen	6	0	0	0	10	0	9	0	43	0	0	0	0
Quaking aspen	68	0	0	0	67	98	67	60	22	173	0	0	0
Basswood	58	0	0	0	27	57	37	103	99	0	72	0	0
Elm	63	0	0	0	36	31	52	100	161	0	142	0	0
Select hardwoods	15	0	0	0	33	7	7	10	70	51	0	0	0
Other hardwoods	5	0	0	0	20	4	3	7	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	1,106	0	212	301	862	978	1,285	1,246	1,250	989	1,455	0	0
Total all species	1,110	0	212	301	862	993	1,285	1,246	1,250	989	1,455	0	0
Number of plots	69	0	1	2	7	18	17	14	5	2	3	0	0
Standard error[3]	60	0	R	95	173	115	112	105	218	278	423	0	0
Average basal area	91	0	30	55	76	89	99	96	95	94	100	0	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 166.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Central Hardwood Unit, Minnesota, 1977[1]

Oak-hickory forest type - Site index class 71-80

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	12	0	0	0	0	0	44	0	0	0	0	0	0
Red pine	5	0	0	0	15	0	0	0	0	0	0	0	0
Jack pine	0	0	0	0	0	0	0	0	0	0	0	0	0
White spruce	0	0	0	0	0	0	0	0	0	0	0	0	0
Black spruce	0	0	0	0	0	0	0	0	0	0	0	0	0
Balsam fir	0	0	0	0	0	0	0	0	0	0	0	0	0
Tamarack	0	0	0	0	0	0	0	0	0	0	0	0	0
Northern white-cedar	0	0	0	0	0	0	0	0	0	0	0	0	0
Other softwoods	6	0	0	0	19	0	0	0	0	0	0	0	0
Total	22	0	0	0	34	0	44	0	0	0	0	0	0
Hardwoods:													
Select white oaks	242	0	0	0	136	245	341	298	0	309	0	0	0
Select red oaks	596	0	0	0	298	684	832	852	0	0	0	0	0
Other red oaks	60	0	0	0	83	0	56	101	0	0	0	0	0
Hickory	51	0	0	0	91	0	52	50	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	2	0	0	0	6	0	0	0	0	0	0	0	0
Soft maple	2	0	0	0	0	11	0	0	0	0	0	0	0
Ash	6	0	0	0	11	9	6	0	0	0	0	0	0
Balsam poplar	3	0	0	0	0	0	11	0	0	0	0	0	0
Paper birch	52	0	0	0	55	95	73	0	0	0	0	0	0
Bigtooth aspen	9	0	0	0	16	13	10	0	0	0	0	0	0
Quaking aspen	60	0	0	0	71	127	49	21	0	0	0	0	0
Basswood	37	0	0	0	15	62	50	45	0	0	0	0	0
Elm	130	0	0	0	76	111	133	209	0	327	0	0	0
Select hardwoods	37	0	265	0	11	41	25	50	0	44	0	0	0
Other hardwoods	4	0	105	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	1,290	0	370	0	869	1,397	1,638	1,626	0	679	0	0	0
Total all species	1,312	0	370	0	903	1,397	1,682	1,626	0	679	0	0	0
Number of plots	30	0	1	0	9	5	8	6	0	1	0	0	0
Standard error[3]	101	0	R	0	100	269	167	136	0	R	0	0	0
Average basal area	94	0	41	0	84	101	110	98	0	52	0	0	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 167.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Central Hardwood Unit, Minnesota, 1977[1]

Oak-hickory forest type - All site index classes

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	2	0	2	0	0	1	6	0	4	0	0	0	0
Red pine	3	0	7	0	5	4	0	0	2	14	0	1	0
Jack pine	0	0	0	0	0	0	1	0	0	0	0	0	0
White spruce	0	0	0	0	0	1	0	0	0	0	0	0	0
Black spruce	0	0	0	0	0	0	0	0	0	0	0	0	0
Balsam fir	0	0	0	0	0	0	0	0	0	0	0	0	0
Tamarack	0	0	0	0	0	0	0	0	0	0	0	0	0
Northern white-cedar	0	0	0	0	0	0	0	0	0	0	0	0	0
Other softwoods	3	0	0	0	10	0	1	10	2	2	2	0	0
Total	8	0	9	0	15	6	8	10	8	16	2	1	0
Hardwoods:													
Select white oaks	212	43	82	57	149	154	230	228	161	303	249	292	255
Select red oaks	446	91	122	85	402	514	558	469	501	376	433	419	361
Other red oaks	15	13	0	0	30	2	20	17	16	12	31	8	0
Hickory	22	0	10	15	63	24	25	39	2	4	18	18	9
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	7	0	3	0	2	6	4	9	4	8	8	22	0
Soft maple	4	0	0	0	0	10	6	1	5	2	3	9	0
Ash	10	0	0	0	14	10	14	8	19	8	10	2	0
Balsam poplar	1	0	0	0	0	1	2	0	5	1	2	0	0
Paper birch	41	15	6	51	47	64	71	46	25	23	25	26	0
Bigtooth aspen	9	0	4	0	9	22	7	9	12	6	3	0	0
Quaking aspen	43	11	5	0	80	105	51	35	45	20	20	14	0
Basswood	32	10	0	0	15	40	36	37	29	17	39	52	29
Elm	55	21	11	20	64	42	45	75	57	59	63	53	37
Select hardwoods	15	0	19	0	15	14	13	15	13	22	13	14	6
Other hardwoods	5	0	8	0	8	3	2	9	6	10	1	3	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	916	204	268	228	898	1,011	1,082	997	899	870	918	934	698
Total all species	924	204	277	228	913	1,017	1,090	1,007	907	885	919	935	698
Number of plots	398	6	14	4	25	53	56	70	46	45	47	27	5
Standard error	25	71	17	60	99	80	72	55	61	69	66	98	113
Average basal area	86	40	51	42	84	89	90	88	93	83	89	89	86

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

Table 168.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Central Hardwood Unit, Minnesota, 1977[1]

Elm-ash-cottonwood forest type - Site index class 0-50

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	2	0	0	0	0	0	0	0	0	0	10	0	0
Red pine	0	0	0	0	0	0	0	0	0	0	0	0	0
Jack pine	0	0	0	0	0	0	0	0	0	0	0	0	0
White spruce	4	0	33	0	0	0	0	0	0	0	0	0	0
Black spruce	0	0	0	0	0	0	0	0	0	0	0	0	0
Balsam fir	2	0	0	0	0	0	0	0	0	0	6	39	0
Tamarack	17	0	26	0	0	0	0	0	393	0	0	0	0
Northern white-cedar	0	0	0	0	0	0	0	0	0	0	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	25	0	59	0	0	0	0	0	393	0	17	39	0
Hardwoods:													
Select white oaks	11	6	0	0	0	0	16	0	0	0	50	0	0
Select red oaks	2	6	0	0	0	0	0	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	4	5	0	0	0	0	0	0	0	0	0	71	0
Soft maple	20	73	0	0	0	0	0	0	0	0	12	0	0
Ash	171	74	53	24	223	441	390	117	198	234	209	133	0
Balsam poplar	0	0	0	0	0	0	0	0	0	0	0	0	0
Paper birch	1	0	0	0	0	0	0	0	0	0	7	0	0
Bigtooth aspen	0	0	0	0	0	0	0	0	0	0	0	0	0
Quaking aspen	28	38	0	0	0	0	0	0	0	0	106	0	0
Basswood	24	0	0	0	0	0	107	0	0	113	25	102	0
Elm	63	19	117	31	220	89	34	34	132	63	86	0	0
Select hardwoods	2	0	0	0	0	0	0	0	0	0	8	0	0
Other hardwoods	11	0	0	0	0	0	0	107	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	337	220	169	55	443	530	547	258	330	410	502	307	0
Total all species	362	220	229	55	443	530	547	258	723	410	519	345	0
Number of plots	28	7	3	1	1	2	2	3	1	2	5	1	0
Standard error[3]	49	63	134	R	R	202	63	133	R	230	168	R	0
Average basal area	57	35	25	8	60	101	92	52	98	62	73	79	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 169.--Cubic foot volume per acre in growing stock trees by species group and stand-age class, Central Hardwood Unit, Minnesota 1977[1]

Elm-ash-cottonwood forest type - Site index class 51-60

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years) 0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	3	0	0	0	0	0	9	9	0	0	0	0	0
Red pine	0	0	0	0	0	0	0	0	0	0	0	0	0
Jack pine	0	0	0	0	0	0	0	0	0	0	0	0	0
White spruce	0	0	0	0	0	0	0	0	0	0	0	0	0
Black spruce	2	0	0	0	0	0	0	0	9	0	0	0	0
Balsam fir	8	0	0	0	0	21	24	0	0	0	0	0	0
Tamarack	6	0	0	0	0	0	0	0	30	0	0	0	0
Northern white-cedar	0	0	0	0	0	0	0	0	0	0	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	19	0	0	0	0	21	33	9	38	0	0	0	0
Hardwoods:													
Select white oaks	26	0	0	0	0	0	0	0	66	0	212	0	0
Select red oaks	1	0	0	0	47	0	0	0	0	0	0	0	0
Other red oaks	6	0	0	0	0	0	0	0	33	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	2	0	0	0	0	0	0	0	0	0	0	0	64
Hard maple	3	0	0	0	0	10	8	0	0	0	0	0	0
Soft maple	48	0	16	0	0	16	34	0	8	0	562	0	0
Ash	296	0	139	35	226	473	319	328	216	498	55	0	1,075
Balsam poplar	0	0	0	0	0	0	0	0	0	0	0	0	0
Paper birch	7	0	0	62	0	0	0	0	8	58	0	0	0
Bigtooth aspen	0	0	0	0	0	0	0	0	0	0	0	0	0
Quaking aspen	12	0	0	0	0	29	38	0	0	0	0	0	0
Basswood	10	0	20	31	47	0	0	0	27	0	0	0	0
Elm	139	0	158	113	59	113	99	81	167	283	377	0	98
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	37	0	0	157	0	39	0	137	5	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	587	0	332	398	379	679	498	546	529	840	1,206	0	1,237
Total all species	605	0	332	398	379	701	531	555	568	840	1,206	0	1,237
Number of plots	32	0	3	2	1	4	7	5	6	1	2	0	1
Standard error[3]	65	0	94	142	R	139	100	137	118	R	714	0	R
Average basal area	71	0	47	43	75	90	64	68	68	94	88	0	146

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 170.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Central Hardwood Unit, Minnesota, 1977[1]

Elm-ash-cottonwood forest type - Site index class 61-70

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	0	0	0	0	0	0	0	0	0	0	0	0	0
Red pine	0	0	0	0	0	0	0	0	0	0	0	0	0
Jack pine	0	0	0	0	0	0	0	0	0	0	0	0	0
White spruce	6	0	83	0	0	0	0	0	0	0	0	0	0
Black spruce	0	0	0	0	0	0	0	0	0	0	0	0	0
Balsam fir	0	0	0	0	0	0	0	0	0	0	0	0	0
Tamarack	0	0	0	0	0	0	0	0	0	0	0	0	0
Northern white-cedar	0	0	0	0	0	0	0	0	0	0	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	6	0	83	0	0	0	0	0	0	0	0	0	0
Hardwoods:													
Select white oaks	5	67	0	0	0	0	0	0	0	0	0	0	0
Select red oaks	15	0	0	0	0	72	0	13	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	6	0	0	0	0	0	0	20	0	0	0	0	0
Hard maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Soft maple	288	0	0	0	0	151	119	375	911	0	0	0	0
Ash	158	0	204	0	234	270	0	195	149	0	0	0	0
Balsam poplar	0	0	0	0	0	0	0	0	0	0	0	0	0
Paper birch	40	0	0	0	0	70	0	95	0	0	0	0	0
Bigtooth aspen	0	0	0	0	0	0	0	0	0	0	0	0	0
Quaking aspen	0	0	0	0	0	0	0	0	0	0	0	0	0
Basswood	11	0	0	0	0	74	0	0	0	0	0	0	0
Elm	124	125	0	0	179	182	0	15	439	0	0	0	0
Select hardwoods	11	54	0	40	0	0	0	13	0	0	0	0	0
Other hardwoods	159	110	0	314	0	365	380	78	113	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	818	356	204	354	413	1,183	499	804	1,613	0	0	0	0
Total all species	824	356	287	354	413	1,183	499	804	1,613	0	0	0	0
Number of plots	13	1	1	1	1	2	1	4	2	0	0	0	0
Standard error[3]	151	R	R	R	R	305	R	255	225	0	0	0	0
Average basal area	76	60	45	30	68	98	82	71	113	0	0	0	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 171.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Central Hardwood Unit, Minnesota, 1977[1]

Elm-ash-cottonwood forest type - Site index class 71-80

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	0	0	0	0	0	0	0	0	0	0	0	0	0
Red pine	0	0	0	0	0	0	0	0	0	0	0	0	0
Jack pine	0	0	0	0	0	0	0	0	0	0	0	0	0
White spruce	0	0	0	0	0	0	0	0	0	0	0	0	0
Black spruce	0	0	0	0	0	0	0	0	0	0	0	0	0
Balsam fir	0	0	0	0	0	0	0	0	0	0	0	0	0
Tamarack	0	0	0	0	0	0	0	0	0	0	0	0	0
Northern white-cedar	0	0	0	0	0	0	0	0	0	0	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	0	0	0	0	0	0	0	0	0	0	0	0	0
Hardwoods:													
Select white oaks	12	0	0	0	0	0	49	0	0	0	0	0	0
Select red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	10	0	0	0	0	0	0	0	123	0	0	0	0
Soft maple	395	0	0	0	0	729	145	822	561	0	0	0	0
Ash	233	0	21	0	0	334	303	102	406	0	0	0	0
Balsam poplar	0	0	0	0	0	0	0	0	0	0	0	0	0
Paper birch	7	0	0	0	0	0	26	0	0	0	0	0	0
Bigtooth aspen	0	0	0	0	0	0	0	0	0	0	0	0	0
Quaking aspen	10	0	57	0	0	0	0	0	0	0	0	0	0
Basswood	23	0	0	0	0	0	92	0	0	0	0	0	0
Elm	207	0	62	91	0	94	305	487	494	0	0	0	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	354	0	20	436	0	452	555	199	95	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	1,250	0	160	527	0	1,609	1,475	1,610	1,679	0	0	0	0
Total all species	1,250	0	160	527	0	1,609	1,475	1,610	1,679	0	0	0	0
Number of plots	12	0	2	1	0	4	3	1	1	0	0	0	0
Standard error[3]	274	0	4	R	0	624	474	R	R	0	0	0	0
Average basal area	101	0	36	86	0	117	113	109	135	0	0	0	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 172.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Central Hardwood Unit, Minnesota, 1977[1]

Elm-ash-cottonwood forest type - All site index classes

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	2	0	0	0	0	0	4	3	0	0	7	0	0
Red pine	0	0	0	0	0	0	0	0	0	0	0	0	0
Jack pine	0	0	0	0	0	0	0	0	0	0	0	0	0
White spruce	2	0	20	0	0	0	0	0	0	0	0	0	0
Black spruce	1	0	0	0	0	0	0	0	5	0	0	0	0
Balsam fir	4	0	0	0	0	7	11	0	0	0	4	39	0
Tamarack	7	0	9	0	0	0	0	0	57	0	0	0	0
Northern white-cedar	0	0	0	0	0	0	0	0	0	0	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	15	0	29	0	0	7	15	3	62	0	12	39	0
Hardwoods:													
Select white oaks	15	13	0	0	0	0	11	0	39	0	96	0	0
Select red oaks	3	5	0	0	16	12	0	4	0	0	0	0	0
Other red oaks	2	0	0	0	0	0	0	0	20	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	2	0	0	0	0	0	0	6	0	0	0	0	64
Hard maple	6	5	0	0	0	3	14	0	12	0	0	71	0
Soft maple	133	64	5	0	0	274	50	254	243	0	169	0	0
Ash	215	65	91	19	228	387	245	211	220	322	165	133	1,075
Balsam poplar	0	0	0	0	0	0	0	0	0	0	0	0	0
Paper birch	10	0	0	25	0	12	5	27	5	19	5	0	0
Bigtooth aspen	0	0	0	0	0	0	0	0	0	0	0	0	0
Quaking aspen	15	33	13	0	0	10	17	0	0	0	76	0	0
Basswood	16	0	7	12	16	12	31	0	16	75	18	102	0
Elm	130	32	105	69	153	114	110	159	250	137	169	0	98
Select hardwoods	2	7	0	8	0	0	0	4	0	0	6	0	0
Other hardwoods	121	14	4	213	0	224	310	108	35	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	669	237	225	346	412	1,048	792	773	841	553	703	307	1,237
Total all species	684	237	254	346	412	1,055	807	776	904	553	715	345	1,237
Number of plots	89	8	9	5	3	12	16	14	10	3	7	1	1
Standard error[3]	63	57	53	90	19	238	136	181	177	195	232	R	R
Average basal area	72	38	37	42	68	102	80	73	87	73	78	79	146

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 173.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Central Hardwood Unit, Minnesota, 1977[1]

Maple-basswood forest type - Site index class 0-50

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	1	0	0	0	0	0	0	0	0	0	0	11	0
Red pine	0	0	0	0	0	0	0	0	0	0	0	0	0
Jack pine	0	0	0	0	0	0	0	0	0	0	0	0	0
White spruce	0	0	0	0	0	0	0	0	0	0	0	0	0
Black spruce	0	0	0	0	0	0	0	0	0	0	0	0	0
Balsam fir	4	0	0	0	0	0	0	0	0	0	0	35	0
Tamarack	3	0	67	0	0	0	0	0	0	0	0	0	0
Northern white-cedar	0	0	0	0	0	0	0	0	0	0	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	9	0	67	0	0	0	0	0	0	0	0	45	0
Hardwoods:													
Select white oaks	35	32	9	0	30	9	101	49	8	51	0	19	0
Select red oaks	35	0	0	8	0	0	104	37	0	53	65	30	0
Other red oaks	1	0	0	0	0	0	0	0	11	0	0	0	0
Hickory	5	17	0	0	0	0	12	0	13	0	0	11	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	75	0	0	30	0	0	13	66	18	50	196	300	0
Soft maple	13	0	0	0	0	20	4	25	0	16	25	16	73
Ash	54	6	0	27	45	0	84	101	126	65	17	55	0
Balsam poplar	5	0	0	0	0	10	0	15	0	8	11	0	0
Paper birch	17	0	0	0	69	8	0	34	0	12	42	14	82
Bigtooth aspen	4	0	0	0	0	0	0	19	0	0	22	0	0
Quaking aspen	27	0	0	30	9	66	42	6	8	14	7	5	752
Basswood	102	5	0	0	0	40	124	173	23	152	51	176	687
Elm	162	75	61	262	166	101	143	127	139	229	173	220	69
Select hardwoods	7	8	0	0	0	10	10	12	0	0	26	3	0
Other hardwoods	17	13	0	14	0	57	0	67	25	8	0	5	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	558	155	70	372	319	321	638	729	371	656	636	855	1,662
Total all species	567	155	137	372	319	321	638	729	371	656	636	900	1,662
Number of plots	71	6	3	3	4	5	8	8	5	13	6	9	1
Standard error[3]	48	57	52	181	117	38	155	156	124	82	132	129	R
Average basal area	69	25	46	53	52	68	77	79	53	82	71	83	139

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 174.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Central Hardwood Unit, Minnesota 1977[1]

Maple-basswood forest type - Site index class 51-60

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)										
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	3	0	0	0	0	0	0	17	0	0	0	0	0
Red pine	0	0	0	0	0	0	0	0	0	0	0	0	0
Jack pine	0	0	0	0	0	0	0	0	0	0	0	0	0
White spruce	0	0	0	0	0	0	0	2	0	0	0	0	0
Black spruce	0	0	0	0	0	0	0	0	2	0	0	0	0
Balsam fir	0	0	0	0	0	0	0	0	2	0	0	0	0
Tamarack	8	0	0	73	26	0	5	0	19	0	0	0	0
Northern white-cedar	0	0	0	0	0	0	0	0	0	0	0	0	0
Other softwoods	3	0	0	0	0	0	0	0	0	10	42	0	0
Total	15	0	0	73	26	0	5	19	23	10	42	0	0
Hardwoods:													
Select white oaks	61	53	0	0	50	45	27	95	87	22	73	116	0
Select red oaks	59	86	45	69	46	71	34	45	70	85	61	59	0
Other red oaks	1	0	0	0	0	6	3	0	0	0	0	0	0
Hickory	3	0	0	0	0	15	0	6	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	77	36	0	0	7	27	97	102	104	108	70	102	644
Soft maple	20	0	30	0	0	24	37	11	40	11	26	0	0
Ash	56	16	48	13	35	18	25	88	82	98	28	83	0
Balsam poplar	5	0	0	0	7	12	0	3	8	10	0	0	0
Paper birch	28	11	11	19	51	48	34	26	26	24	0	12	0
Bigtooth aspen	4	0	0	0	0	6	0	0	12	0	12	0	0
Quaking aspen	34	6	25	169	22	62	27	12	59	0	22	0	0
Basswood	191	46	0	0	33	152	170	267	210	265	296	419	381
Elm	206	111	50	40	149	166	236	125	296	304	176	531	140
Select hardwoods	6	0	0	0	0	5	17	17	2	0	0	0	0
Other hardwoods	6	0	0	0	0	4	13	3	18	0	0	8	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	759	365	210	310	400	660	721	800	1,013	927	765	1,330	1,165
Total all species	774	365	210	383	426	660	726	819	1,036	937	807	1,330	1,165
Number of plots	115	6	4	3	9	17	12	22	22	9	5	5	1
Standard error[3]	41	67	72	117	53	76	141	84	81	187	116	231	R
Average basal area	78	51	40	58	57	72	77	84	95	86	79	97	94

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 175.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Central Hardwood Unit, Minnesota, 1977[1]

Maple-basswood forest type - Site index class 61-70

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	4	0	11	0	0	0	0	0	0	0	67	0	0
Red pine	0	0	0	0	0	0	0	0	0	0	0	0	0
Jack pine	0	0	0	0	0	0	0	0	0	0	0	0	0
White spruce	3	0	0	0	0	0	0	11	0	0	0	0	0
Black spruce	0	0	0	0	0	0	0	0	0	0	0	0	0
Balsam fir	1	0	0	0	0	0	0	3	0	0	0	0	0
Tamarack	3	0	0	39	0	3	0	0	0	16	0	0	0
Northern white-cedar	0	0	0	0	0	0	0	0	0	0	0	0	0
Other softwoods	4	0	0	0	0	0	0	16	0	0	0	0	0
Total	13	0	11	39	0	3	0	30	0	16	67	0	0
Hardwoods:													
Select white oaks	83	0	26	31	42	50	36	101	105	236	124	111	0
Select red oaks	90	0	27	24	80	100	182	66	55	84	0	230	0
Other red oaks	1	0	0	0	0	0	0	0	0	10	0	0	0
Hickory	3	0	15	0	0	0	0	0	0	32	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	107	0	0	0	200	62	128	78	170	75	23	328	0
Soft maple	24	0	22	0	33	44	30	34	4	0	13	37	0
Ash	87	0	11	62	130	79	117	113	71	0	49	143	0
Balsam poplar	0	0	0	0	0	0	0	0	0	0	0	0	0
Paper birch	43	0	10	0	59	12	95	19	64	0	0	137	0
Bigtooth aspen	7	0	0	0	0	18	12	2	10	14	0	0	0
Quaking aspen	34	499	76	0	142	49	31	15	0	0	0	21	0
Basswood	242	0	99	0	104	212	257	150	492	331	321	240	0
Elm	266	0	7	19	72	261	176	326	415	499	259	300	0
Select hardwoods	12	0	0	13	7	5	6	26	13	0	25	0	0
Other hardwoods	29	0	0	28	6	27	26	34	45	0	99	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	1,028	499	292	176	876	918	1,095	964	1,444	1,281	912	1,545	0
Total all species	1,041	499	303	215	876	921	1,095	994	1,444	1,297	979	1,545	0
Number of plots	96	1	5	3	6	12	17	22	15	6	5	4	0
Standard error[3]	56	R	40	78	117	102	98	87	180	286	133	321	0
Average basal area	87	64	46	39	85	86	95	84	104	83	84	110	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 176.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Central Hardwood Unit, Minnesota, 1977[1]

Maple-basswood forest type - Site index class 71-80

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)										
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	25	0	0	0	0	0	0	107	0	0	0	0	0
Red pine	0	0	0	0	0	0	0	0	0	0	0	0	0
Jack pine	0	0	0	0	0	0	0	0	0	0	0	0	0
White spruce	0	0	0	0	0	0	0	0	0	0	0	0	0
Black spruce	0	0	0	0	0	0	0	0	0	0	0	0	0
Balsam fir	0	0	0	0	0	0	0	0	0	0	0	0	0
Tamarack	0	0	0	0	0	0	0	0	0	0	0	0	0
Northern white-cedar	0	0	0	0	0	0	0	0	0	0	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	25	0	0	0	0	0	0	107	0	0	0	0	0
Hardwoods:													
Select white oaks	68	0	0	87	91	60	127	31	92	0	0	0	0
Select red oaks	90	0	0	135	85	26	54	98	141	224	120	0	0
Other red oaks	8	0	0	0	0	58	0	0	0	0	0	0	0
Hickory	9	0	0	0	15	13	10	0	22	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	164	0	56	118	55	104	134	145	398	447	167	0	0
Soft maple	6	0	0	0	0	0	17	13	0	0	0	0	0
Ash	58	0	0	29	124	88	24	45	68	0	0	0	0
Balsam poplar	0	0	0	0	0	0	0	0	0	0	0	0	0
Paper birch	42	0	0	271	59	35	27	31	0	0	0	0	0
Bigtooth aspen	4	0	0	30	0	0	0	10	0	0	0	0	0
Quaking aspen	65	0	0	107	140	63	63	65	0	0	0	0	0
Basswood	293	0	0	204	265	207	167	351	668	249	253	0	0
Elm	325	0	162	234	183	270	341	369	464	675	99	0	0
Select hardwoods	10	0	0	24	9	28	12	6	0	0	0	0	0
Other hardwoods	39	0	0	0	0	13	107	17	81	101	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	1,182	0	218	1,240	1,025	965	1,083	1,180	1,933	1,695	639	0	0
Total all species	1,207	0	218	1,240	1,025	965	1,083	1,288	1,933	1,695	639	0	0
Number of plots	35	0	1	2	6	5	6	8	4	2	1	0	0
Standard error[3]	103	0	R	306	223	232	153	231	368	3	R	0	0
Average basal area	89	0	23	87	76	92	94	88	128	90	64	0	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 177.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Central Hardwood Unit, Minnesota, 1977[1]

Maple-basswood forest type - Site index class 81-90

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	0	0	0	0	0	0	0	0	0	0	0	0	0
Red pine	0	0	0	0	0	0	0	0	0	0	0	0	0
Jack pine	0	0	0	0	0	0	0	0	0	0	0	0	0
White spruce	0	0	0	0	0	0	0	0	0	0	0	0	0
Black spruce	0	0	0	0	0	0	0	0	0	0	0	0	0
Balsam fir	0	0	0	0	0	0	0	0	0	0	0	0	0
Tamarack	0	0	0	0	0	0	0	0	0	0	0	0	0
Northern white-cedar	0	0	0	0	0	0	0	0	0	0	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	0	0	0	0	0	0	0	0	0	0	0	0	0
Hardwoods:													
Select white oaks	75	0	0	0	0	41	152	20	0	0	0	0	0
Select red oaks	131	0	0	0	0	239	220	0	0	0	0	0	0
Other red oaks	39	0	0	0	0	236	0	0	0	0	0	0	0
Hickory	38	0	0	0	0	115	0	76	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	54	0	0	0	68	209	32	0	0	0	0	0	0
Soft maple	100	0	0	0	189	56	141	62	0	0	0	0	0
Ash	120	0	0	0	384	0	25	291	0	59	0	0	0
Balsam poplar	0	0	0	0	0	0	0	0	0	0	0	0	0
Paper birch	27	0	0	0	0	164	0	0	0	0	0	0	0
Bigtooth aspen	53	0	0	0	100	144	49	0	0	0	0	0	0
Quaking aspen	63	0	0	0	0	252	50	0	0	0	0	0	0
Basswood	350	0	0	0	697	1,124	195	92	0	0	0	0	0
Elm	571	0	0	0	386	0	878	504	0	564	0	0	0
Select hardwoods	18	0	0	0	0	0	43	0	0	0	0	0	0
Other hardwoods	61	0	0	0	0	0	125	0	0	102	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	1,699	0	0	0	1,823	2,580	1,910	1,045	0	724	0	0	0
Total all species	1,699	0	0	0	1,823	2,580	1,910	1,045	0	724	0	0	0
Number of plots	12	0	0	0	1	2	5	3	0	1	0	0	0
Standard error[3]	233	0	0	0	R	680	193	498	0	R	0	0	0
Average basal area	106	0	0	0	128	148	117	72	0	49	0	0	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 178.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Central Hardwood Unit, Minnesota, 1977[1]

Maple-basswood forest type - All site index classes

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)										
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	5	0	4	0	0	0	0	20	0	0	20	5	0
Red pine	0	0	0	0	0	0	0	0	0	0	0	0	0
Jack pine	0	0	0	0	0	0	0	0	0	0	0	0	0
White spruce	1	0	0	0	0	0	0	5	0	0	0	0	0
Black spruce	0	0	0	0	0	0	0	0	1	0	0	0	0
Balsam fir	1	0	0	0	0	0	0	1	1	0	0	17	0
Tamarack	4	0	15	31	9	1	1	0	9	3	0	0	0
Northern white-cedar	0	0	0	0	0	0	0	0	0	0	0	0	0
Other softwoods	2	0	0	0	0	0	0	6	0	3	12	0	0
Total	14	0	20	31	9	1	1	31	11	6	32	23	0
Hardwoods:													
Select white oaks	63	40	12	24	50	44	68	80	85	73	58	66	0
Select red oaks	69	39	24	52	52	74	120	56	63	78	48	82	0
Other red oaks	3	0	0	0	0	21	1	0	1	2	0	0	0
Hickory	5	8	6	0	3	13	3	6	3	6	0	5	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	95	17	4	30	83	52	92	90	142	96	106	251	322
Soft maple	21	0	18	0	14	28	37	23	20	10	20	16	36
Ash	68	10	19	33	102	41	67	103	82	58	29	82	0
Balsam poplar	3	0	0	0	2	6	0	3	4	6	4	0	0
Paper birch	32	5	7	54	63	37	45	24	34	12	15	41	41
Bigtooth aspen	7	0	0	5	4	15	9	5	9	3	11	0	0
Quaking aspen	37	41	37	74	72	68	38	18	29	6	9	7	376
Basswood	203	24	38	37	122	210	196	216	321	220	214	257	534
Elm	240	86	45	130	149	191	279	245	332	343	195	324	105
Select hardwoods	9	4	0	8	3	8	14	17	5	0	17	2	0
Other hardwoods	21	6	0	11	1	18	39	24	33	13	29	5	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	875	278	210	460	721	825	1,009	909	1,164	925	755	1,140	1,414
Total all species	889	278	229	490	729	826	1,010	939	1,175	931	787	1,163	1,414
Number of plots	330	13	13	11	27	41	48	63	46	31	17	18	2
Standard error	31	52	33	133	93	89	80	61	95	98	74	126	249
Average basal area	81	40	42	56	71	82	90	83	96	83	77	93	117

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

Table 179.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Central Hardwood Unit Minnesota, 1977[1]

Aspen forest type - Site index class 0-50

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years) 0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	0	0	0	0	0	0	0	0	0	0	0	0	0
Red pine	0	0	0	0	0	0	0	0	0	0	0	0	0
Jack pine	0	0	0	0	0	0	0	0	0	0	0	0	0
White spruce	0	0	0	0	0	0	0	0	0	0	0	0	0
Black spruce	0	0	0	0	0	0	0	0	0	0	0	0	0
Balsam fir	0	0	0	0	0	0	0	0	0	0	0	0	0
Tamarack	17	0	0	0	0	0	53	0	0	0	0	0	0
Northern white-cedar	0	0	0	0	0	0	0	0	0	0	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	17	0	0	0	0	0	53	0	0	0	0	0	0
Hardwoods:													
Select white oaks	24	0	24	0	27	0	39	0	0	0	0	0	0
Select red oaks	30	0	0	0	0	294	6	0	0	42	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	5	0	18	0	0	0	0	0	0	0	0	0	0
Soft maple	7	0	0	0	0	77	0	0	0	0	0	0	0
Ash	31	0	0	0	13	0	91	0	0	0	0	0	0
Balsam poplar	0	0	0	0	0	0	0	0	0	0	0	0	0
Paper birch	47	0	37	24	45	95	56	0	0	0	0	0	0
Bigtooth aspen	2	0	0	0	0	0	7	0	0	0	0	0	0
Quaking aspen	161	0	21	54	176	328	267	0	0	72	0	0	0
Basswood	11	0	0	0	0	91	10	0	0	0	0	0	0
Elm	56	0	16	0	9	141	111	0	0	43	0	0	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	375	0	117	78	270	1,025	587	0	0	158	0	0	0
Total all species	392	0	117	78	270	1,025	640	0	0	158	0	0	0
Number of plots	22	0	6	2	4	2	7	0	0	1	0	0	0
Standard error[3]	87	0	71	78	92	234	163	0	0	R	0	0	0
Average basal area	53	0	27	34	62	113	62	0	0	26	0	0	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 180.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Central Hardwood Unit, Minnesota, 1977[1]

Aspen forest type - Site index class 51-60

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years) 0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	1	0	10	0	0	0	0	0	0	0	0	0	0
Red pine	2	0	0	0	0	0	8	0	0	0	0	0	0
Jack pine	5	0	50	0	0	4	0	0	0	0	0	0	0
White spruce	0	0	0	0	0	0	0	0	0	0	0	0	0
Black spruce	4	0	0	27	0	0	7	13	0	0	0	0	0
Balsam fir	3	3	0	0	0	0	9	5	0	0	0	0	0
Tamarack	1	0	0	0	0	0	3	0	0	0	0	0	0
Northern white-cedar	0	0	0	0	0	0	0	0	0	0	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	15	3	60	27	0	4	27	18	0	0	0	0	0
Hardwoods:													
Select white oaks	24	7	0	25	27	42	34	20	0	0	0	0	0
Select red oaks	48	31	9	0	59	72	64	50	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	4	0	0	0	0	4	8	11	0	0	0	0	0
Soft maple	17	0	0	0	16	20	6	80	0	29	0	0	0
Ash	10	0	0	0	5	13	29	6	0	0	0	0	0
Balsam poplar	13	13	0	0	46	7	23	10	0	0	0	0	0
Paper birch	42	13	22	40	31	45	49	93	0	74	0	0	0
Bigtooth aspen	30	9	50	0	12	25	80	0	0	114	0	0	0
Quaking aspen	274	68	88	236	345	405	324	416	0	67	0	0	0
Basswood	17	0	22	11	0	33	30	0	0	0	0	0	0
Elm	26	5	0	42	0	19	65	42	0	0	0	0	0
Select hardwoods	2	0	0	0	0	1	3	9	0	0	0	0	0
Other hardwoods	0	0	0	0	0	2	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	508	146	191	354	541	688	716	738	0	285	0	0	0
Total all species	524	149	251	382	541	691	744	755	0	285	0	0	0
Number of plots	93	20	8	5	6	24	18	11	0	1	0	0	0
Standard error[3]	37	32	41	70	113	51	84	124	0	R	0	0	0
Average basal area	62	30	44	71	54	72	78	91	0	34	0	0	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 181.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Central Hardwood Unit, Minnesota, 1977[1]

Aspen forest type - Site index class 61-70

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	1	0	0	0	0	1	3	0	0	0	0	0	0
Red pine	8	0	0	11	5	14	5	0	35	0	0	0	0
Jack pine	4	0	0	45	2	4	2	0	0	0	0	0	0
White spruce	2	10	0	0	0	2	0	0	0	0	0	0	0
Black spruce	0	0	0	0	0	0	0	0	0	0	0	0	0
Balsam fir	6	0	0	0	0	20	0	0	0	0	0	0	0
Tamarack	1	0	0	0	0	4	0	0	0	0	0	0	0
Northern white-cedar	0	0	0	0	0	0	0	0	0	0	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	22	10	0	56	7	45	10	0	35	0	0	0	0
Hardwoods:													
Select white oaks	24	2	47	8	21	21	34	26	79	129	0	0	0
Select red oaks	58	41	34	0	66	52	54	77	153	576	0	0	0
Other red oaks	2	0	0	0	7	0	4	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	6	4	0	0	12	1	5	8	62	0	0	0	0
Soft maple	12	15	9	0	6	19	9	11	17	0	0	0	0
Ash	12	0	20	4	9	12	6	63	52	0	0	0	0
Balsam poplar	9	0	0	6	19	8	11	0	14	0	0	0	0
Paper birch	68	14	16	31	71	95	70	87	128	0	0	0	0
Bigtooth aspen	47	7	0	0	21	114	36	0	36	0	0	0	0
Quaking aspen	374	92	166	308	358	427	584	467	302	261	0	0	0
Basswood	24	29	40	0	25	11	34	0	118	0	0	0	0
Elm	20	0	0	23	10	12	38	69	117	0	0	0	0
Select hardwoods	2	0	0	0	1	2	4	0	0	0	0	0	0
Other hardwoods	2	0	0	0	6	4	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	662	203	332	380	630	778	890	806	1,076	966	0	0	0
Total all species	684	213	332	436	638	823	900	806	1,111	966	0	0	0
Number of plots	162	19	9	8	38	49	27	6	5	1	0	0	0
Standard error[3]	29	54	83	86	45	43	55	136	240	R	0	0	0
Average basal area	68	31	53	55	66	79	84	61	90	64	0	0	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 182.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Central Hardwood Unit, Minnesota 1977[1]

Aspen forest type - Site index class 71-80

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	8	0	0	0	8	0	92	0	228	0	0	0	0
Red pine	8	22	0	28	3	0	0	0	0	0	0	0	0
Jack pine	4	0	22	0	6	0	0	0	0	0	0	0	0
White spruce	0	0	0	0	0	0	0	0	0	0	0	0	0
Black spruce	0	0	0	0	0	0	0	0	0	0	0	0	0
Balsam fir	2	0	0	0	0	10	0	0	0	0	0	0	0
Tamarack	4	0	23	15	0	0	0	0	0	0	0	0	0
Northern white-cedar	0	0	0	0	0	0	0	0	0	0	0	0	0
Other softwoods	0	0	3	0	0	0	0	0	0	0	0	0	0
Total	27	22	48	43	17	10	92	0	228	0	0	0	0
Hardwoods:													
Select white oaks	35	32	10	19	40	44	42	80	0	0	0	0	0
Select red oaks	76	9	19	60	92	73	245	403	361	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	6	0	0	0	3	13	14	69	63	0	0	0	0
Soft maple	16	7	0	12	16	25	12	0	102	0	0	0	0
Ash	13	16	0	18	16	3	56	0	0	0	0	0	0
Balsam poplar	12	21	24	7	13	6	0	0	0	0	0	0	0
Paper birch	87	17	37	120	68	133	83	431	187	0	0	0	0
Bigtooth aspen	36	0	0	0	51	54	140	0	0	0	0	0	0
Quaking aspen	439	112	87	412	602	551	243	296	1,652	0	0	0	0
Basswood	21	26	6	11	21	19	102	0	0	0	0	0	0
Elm	21	27	0	22	18	30	31	0	0	0	0	0	0
Select hardwoods	4	0	0	11	1	7	0	0	0	0	0	0	0
Other hardwoods	6	0	46	4	3	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	770	267	230	697	945	957	968	1,278	2,365	0	0	0	0
Total all species	797	289	278	739	962	967	1,060	1,278	2,593	0	0	0	0
Number of plots	101	15	9	13	32	26	4	1	1	0	0	0	0
Standard error[3]	45	30	80	82	61	72	183	R	R	0	0	0	0
Average basal area	69	30	46	76	78	79	86	105	128	0	0	0	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 183.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Central Hardwood Unit, Minnesota, 1977[1]

Aspen forest type - Site index class 81-90

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years) 0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	12	0	0	0	33	0	0	0	0	0	0	0	0
Red pine	0	0	0	0	0	0	0	0	0	0	0	0	0
Jack pine	0	0	0	0	0	0	0	0	0	0	0	0	0
White spruce	0	0	0	0	0	0	0	0	0	0	0	0	0
Black spruce	0	0	0	0	0	0	0	0	0	0	0	0	0
Balsam fir	0	0	0	0	0	0	0	0	0	0	0	0	0
Tamarack	14	0	0	0	36	0	0	0	0	0	0	0	0
Northern white-cedar	0	0	0	0	0	0	0	0	0	0	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	26	0	0	0	68	0	0	0	0	0	0	0	0
Hardwoods:													
Select white oaks	25	0	86	17	22	18	32	0	0	0	0	0	0
Select red oaks	137	0	0	30	138	368	117	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	9	0	0	0	16	13	0	0	0	0	0	0	0
Soft maple	34	0	109	0	10	40	130	0	0	0	0	0	0
Ash	13	0	37	0	7	35	0	0	0	0	0	0	0
Balsam poplar	5	0	0	0	0	0	52	0	0	0	0	0	0
Paper birch	120	108	44	201	157	67	87	0	0	0	0	0	0
Bigtooth aspen	67	36	0	0	70	184	0	0	0	0	0	0	0
Quaking aspen	472	169	392	141	583	644	545	0	0	0	0	0	0
Basswood	32	0	0	0	42	63	39	0	0	0	0	0	0
Elm	14	0	45	0	26	0	0	0	0	0	0	0	0
Select hardwoods	5	0	0	0	6	0	30	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	931	312	714	388	1,077	1,433	1,032	0	0	0	0	0	0
Total all species	957	312	714	388	1,145	1,433	1,032	0	0	0	0	0	0
Number of plots	21	3	2	2	8	4	2	0	0	0	0	0	0
Standard error	103	183	249	107	101	103	306	0	0	0	0	0	0
Average basal area	74	30	79	42	81	99	94	0	0	0	0	0	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

Table 186.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Central Hardwood Unit, Minnesota, 1977[1]

Paper birch forest type - Site index class 51-60

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	9	0	0	0	0	0	52	0	0	0	0	0	0
Red pine	0	0	0	0	0	0	0	0	0	0	0	0	0
Jack pine	0	0	0	0	0	0	0	0	0	0	0	0	0
White spruce	3	0	0	0	0	0	17	0	0	0	0	0	0
Black spruce	2	0	0	0	0	7	0	0	0	0	0	0	0
Balsam fir	11	0	0	0	0	8	53	0	0	0	0	0	0
Tamarack	6	0	0	0	0	22	0	0	0	0	0	0	0
Northern white-cedar	0	0	0	0	0	0	0	0	0	0	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	30	0	0	0	0	37	122	0	0	0	0	0	0
Hardwoods:													
Select white oaks	33	0	0	23	0	10	0	29	0	414	0	0	0
Select red oaks	79	0	0	16	104	0	158	350	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	19	0	0	0	0	0	0	170	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Soft maple	15	0	36	0	0	38	0	0	0	0	0	0	0
Ash	12	0	0	0	0	24	31	0	0	0	0	0	0
Balsam poplar	9	0	0	16	0	21	0	0	0	0	0	0	0
Paper birch	383	0	116	132	745	389	368	723	0	290	0	0	0
Bigtooth aspen	17	0	0	86	0	0	19	0	0	0	0	0	0
Quaking aspen	63	0	0	73	49	68	0	236	0	0	0	0	0
Basswood	13	0	0	0	24	0	0	0	0	193	0	0	0
Elm	41	0	0	36	25	71	30	72	0	0	0	0	0
Select hardwoods	4	0	0	0	33	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	688	0	152	381	979	620	605	1,580	0	898	0	0	0
Total all species	718	0	152	381	979	657	727	1,580	0	898	0	0	0
Number of plots	18	0	2	3	2	5	3	2	0	1	0	0	0
Standard error[3]	109	0	152	66	193	100	203	422	0	R	0	0	0
Average basal area	75	0	44	65	96	65	88	96	0	94	0	0	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 187.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Central Hardwood Unit, Minnesota, 1977[1]

Paper birch forest type - Site index class 61-70

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years) 0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	19	0	0	0	36	0	0	0	112	0	0	0	0
Red pine	30	0	0	0	0	0	0	0	275	86	0	0	0
Jack pine	8	0	0	0	23	9	0	0	0	0	0	0	0
White spruce	0	0	0	0	0	0	0	0	0	0	0	0	0
Black spruce	0	0	0	0	0	0	0	0	0	0	0	0	0
Balsam fir	17	0	0	0	0	30	29	0	0	0	0	0	0
Tamarack	14	0	0	0	60	0	0	0	0	0	0	0	0
Northern white-cedar	0	0	0	0	0	0	0	0	0	0	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	89	0	0	0	119	39	29	0	387	86	0	0	0
Hardwoods:													
Select white oaks	22	0	0	0	27	17	40	0	0	0	0	0	0
Select red oaks	94	0	0	0	11	31	117	342	208	351	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	4	0	0	0	0	0	0	0	47	0	0	0	0
Soft maple	24	0	0	0	0	43	34	0	21	0	0	0	0
Ash	34	0	0	0	17	79	18	0	0	0	0	0	0
Balsam poplar	3	0	0	0	0	0	13	0	0	0	0	0	0
Paper birch	494	0	0	0	323	627	569	261	181	905	0	0	0
Bigtooth aspen	25	0	0	0	0	10	0	0	0	462	0	0	0
Quaking aspen	159	0	0	0	115	158	279	0	127	0	0	0	0
Basswood	28	0	0	0	28	0	48	0	103	0	0	0	0
Elm	50	0	0	0	94	38	52	49	0	0	0	0	0
Select hardwoods	3	0	0	0	0	0	0	53	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	940	0	0	0	615	1,003	1,170	705	687	1,719	0	0	0
Total all species	1,029	0	0	0	734	1,042	1,199	705	1,074	1,804	0	0	0
Number of plots	21	0	0	0	5	7	5	1	2	1	0	0	0
Standard error[3]	83	0	0	0	64	159	152	R	3	R	0	0	0
Average basal area	89	0	0	0	73	86	107	82	94	98	0	0	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 188.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Central Hardwood Unit, Minnesota, 1977[1]

Paper birch forest type - All site index classes

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)										
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	13	0	0	0	15	0	16	0	108	0	0	0	0
Red pine	11	0	0	0	0	0	0	0	137	29	0	0	0
Jack pine	4	0	0	0	9	4	0	0	17	0	0	0	0
White spruce	1	0	0	0	0	0	5	0	0	0	0	0	0
Black spruce	1	0	0	0	0	3	0	0	0	0	0	0	0
Balsam fir	10	0	0	0	3	18	30	0	0	0	0	0	0
Tamarack	9	0	14	0	30	8	0	0	0	0	0	0	0
Northern white-cedar	0	0	0	0	0	0	0	0	0	0	0	0	0
Other softwoods	2	0	0	0	0	0	12	0	0	0	0	0	0
Total	52	0	14	0	57	32	64	0	263	29	0	0	0
Hardwoods:													
Select white oaks	30	0	0	25	15	19	20	19	62	223	0	0	0
Select red oaks	83	101	18	12	69	33	106	347	117	169	0	108	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	8	0	0	0	0	0	9	113	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	2	0	0	0	0	0	0	0	23	0	0	0	0
Soft maple	14	0	15	0	0	38	17	0	11	0	0	0	0
Ash	17	0	0	0	9	48	18	0	0	0	0	0	0
Balsam poplar	5	0	0	23	0	8	6	0	0	0	0	0	0
Paper birch	409	108	56	130	368	663	522	569	105	430	0	86	0
Bigtooth aspen	15	0	0	64	0	5	6	0	0	154	0	0	0
Quaking aspen	100	0	0	55	95	103	190	157	131	0	0	0	0
Basswood	16	0	0	0	24	0	24	0	52	64	0	0	0
Elm	55	0	26	42	57	116	35	65	0	0	0	0	0
Select hardwoods	3	0	0	0	10	0	0	18	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	756	209	114	352	647	1,033	953	1,288	500	1,041	0	194	0
Total all species	809	209	128	352	704	1,065	1,017	1,288	763	1,069	0	194	0
Number of plots	57	1	5	4	12	14	10	3	4	3	0	1	0
Standard error[3]	74	R	57	55	111	175	134	380	218	384	0	R	0
Average basal area	75	19	37	59	68	87	95	91	73	84	0	23	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 189.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Prairie Unit, Minnesota, 1977[1]

Oak-hickory forest type - Site index class 0-50

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years) 0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	0	0	0	0	0	0	0	0	0	0	0	0	0
Red pine	0	0	0	0	0	0	0	0	0	0	0	0	0
Jack pine	0	0	0	0	0	0	0	0	0	0	0	0	0
White spruce	0	0	0	0	0	0	0	0	0	0	0	0	0
Black spruce	0	0	0	0	0	0	0	0	0	0	0	0	0
Balsam fir	0	0	0	0	0	0	0	0	0	0	0	0	0
Tamarack	0	0	0	0	0	0	0	0	0	0	0	0	0
Northern white-cedar	0	0	0	0	0	0	0	0	0	0	0	0	0
Other softwoods	11	0	0	0	0	0	0	0	0	0	47	0	0
Total	11	0	0	0	0	0	0	0	0	0	47	0	0
Hardwoods:													
Select white oaks	603	176	0	0	0	449	142	283	919	804	642	740	0
Select red oaks	60	0	0	0	0	18	510	348	13	0	4	0	0
Other red oaks	3	0	0	0	0	0	0	0	0	0	13	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Soft maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	42	0	0	0	0	0	0	0	17	107	48	0	0
Balsam poplar	4	15	0	0	0	0	0	0	28	0	0	0	0
Paper birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Bigtooth aspen	0	0	0	0	0	0	0	0	0	0	0	0	0
Quaking aspen	40	13	0	0	0	58	286	94	39	23	15	0	0
Basswood	19	0	0	0	0	76	0	0	0	30	6	46	0
Elm	31	0	0	0	0	36	0	26	0	66	32	0	0
Select hardwoods	15	0	0	0	0	0	33	0	0	16	40	0	0
Other hardwoods	14	0	0	0	0	0	0	16	0	35	11	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	830	204	0	0	0	637	971	767	1,016	1,081	812	785	0
Total all species	841	204	0	0	0	637	971	767	1,016	1,081	859	785	0
Number of plots	34	2	1	0	0	3	1	4	4	9	8	2	0
Standard error[3]	82	73	R	0	0	94	R	266	300	187	103	270	0
Average basal area	94	36	19	0	0	104	116	95	118	103	89	87	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 190.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Prairie Unit, Minnesota 1977[1]

Oak-hickory forest type - Site index class 51-60

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	0	0	0	0	0	0	0	0	0	0	0	0	0
Red pine	0	0	0	0	0	0	0	0	0	0	0	0	0
Jack pine	0	0	0	0	0	0	0	0	0	0	0	0	0
White spruce	0	0	0	0	0	0	0	0	0	0	0	0	0
Black spruce	0	0	0	0	0	0	0	0	0	0	0	0	0
Balsam fir	0	0	0	0	0	0	0	0	0	0	0	0	0
Tamarack	0	0	0	0	0	0	0	0	0	0	0	0	0
Northern white-cedar	0	0	0	0	0	0	0	0	0	0	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	0	0	0	0	0	0	0	0	0	0	0	0	0
Hardwoods:													
Select white oaks	295	0	0	0	88	795	0	475	171	0	0	0	0
Select red oaks	226	0	0	0	602	0	451	58	404	0	0	0	0
Other red oaks	11	0	0	0	0	0	0	34	0	0	0	0	0
Hickory	19	0	0	0	0	0	0	56	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Soft maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	7	63	0	0	0	0	0	0	0	0	0	0	0
Balsam poplar	5	0	0	0	0	0	0	16	0	0	0	0	0
Paper birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Bigtooth aspen	0	0	0	0	0	0	0	0	0	0	0	0	0
Quaking aspen	129	0	0	0	902	0	261	0	0	0	0	0	0
Basswood	84	0	0	0	0	0	0	0	376	0	0	0	0
Elm	56	0	0	0	0	0	0	0	250	0	0	0	0
Select hardwoods	21	0	0	0	0	143	0	14	0	0	0	0	0
Other hardwoods	10	0	0	0	0	0	0	0	47	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	862	63	0	0	1,592	938	713	653	1,248	0	0	0	0
Total all species	862	63	0	0	1,592	938	713	653	1,248	0	0	0	0
Number of plots	9	1	0	0	1	1	1	3	2	0	0	0	0
Standard error[3]	222	R	0	0	R	R	R	162	942	0	0	0	0
Average basal area	82	45	0	0	165	82	68	72	79	0	0	0	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 191.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Prairie Unit, Minnesota, 1977[1]

Oak-hickory forest type - All site index classes

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years) 0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	0	0	0	0	0	0	0	0	0	0	0	0	0
Red pine	0	0	0	0	0	0	0	0	0	0	0	0	0
Jack pine	0	0	0	0	0	0	0	0	0	0	0	0	0
White spruce	0	0	0	0	0	0	0	0	0	0	0	0	0
Black spruce	0	0	0	0	0	0	0	0	0	0	0	0	0
Balsam fir	0	0	0	0	0	0	0	0	0	0	0	0	0
Tamarack	0	0	0	0	0	0	0	0	0	0	0	0	0
Northern white-cedar	0	0	0	0	0	0	0	0	0	0	0	0	0
Other softwoods	10	0	0	0	0	0	0	11	0	0	47	0	0
Total	10	0	0	0	0	0	0	11	0	0	47	0	0
Hardwoods:													
Select white oaks	498	88	0	0	88	536	71	329	574	740	642	740	0
Select red oaks	127	54	0	0	602	13	481	202	188	120	4	0	0
Other red oaks	4	0	0	0	0	0	0	13	0	0	13	0	0
Hickory	4	0	0	0	0	0	0	21	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	1	0	0	0	0	0	0	0	9	0	0	0	0
Soft maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	31	16	0	0	0	0	0	0	10	96	48	0	0
Balsam poplar	4	7	0	0	0	0	0	6	16	0	0	0	0
Paper birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Bigtooth aspen	0	0	0	0	0	0	0	0	0	0	0	0	0
Quaking aspen	55	7	0	0	902	44	274	58	23	20	15	0	0
Basswood	44	86	0	0	0	57	0	0	155	27	6	46	0
Elm	44	0	0	0	0	27	0	42	107	60	32	0	0
Select hardwoods	15	0	0	0	0	36	17	5	0	14	40	0	0
Other hardwoods	12	0	0	0	0	0	0	8	13	31	11	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	839	258	0	0	1,592	712	842	684	1,094	1,109	812	785	0
Total all species	849	258	0	0	1,592	712	842	695	1,094	1,109	859	785	0
Number of plots	47	4	1	0	1	4	2	8	7	10	8	2	0
Standard error[3]	73	110	R	0	R	100	129	138	264	170	103	270	0
Average basal area	90	42	19	0	165	98	92	90	100	102	89	87	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 192.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Prairie Unit, Minnesota, 1977[1]

Elm-ash-cottonwood forest type - Site index class 0-50

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	0	0	0	0	0	0	0	0	0	0	0	0	0
Red pine	0	0	0	0	0	0	0	0	0	0	0	0	0
Jack pine	0	0	0	0	0	0	0	0	0	0	0	0	0
White spruce	0	0	0	0	0	0	0	0	0	0	0	0	0
Black spruce	0	0	0	0	0	0	0	0	0	0	0	0	0
Balsam fir	0	0	0	0	0	0	0	0	0	0	0	0	0
Tamarack	0	0	0	0	0	0	0	0	0	0	0	0	0
Northern white-cedar	0	0	0	0	0	0	0	0	0	0	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	0	0	0	0	0	0	0	0	0	0	0	0	0
Hardwoods:													
Select white oaks	8	0	0	0	0	0	22	19	0	0	0	0	0
Select red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Soft maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	129	0	0	0	204	0	381	106	48	140	0	0	0
Balsam poplar	19	0	0	37	0	0	43	21	0	59	0	0	0
Paper birch	34	0	0	0	0	0	0	40	262	60	0	0	0
Bigtooth aspen	0	0	0	0	0	0	0	0	0	0	0	0	0
Quaking aspen	33	0	0	0	0	164	26	0	0	0	43	0	0
Basswood	11	0	0	0	70	0	0	0	0	0	0	0	0
Elm	129	0	0	0	104	0	288	177	177	184	0	0	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	314	0	0	28	11	367	47	690	0	0	1,132	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	675	0	0	65	390	530	808	1,051	486	443	1,176	0	0
Total all species	675	0	0	65	390	530	808	1,051	486	443	1,176	0	0
Number of plots	13	0	0	1	2	2	2	3	1	1	1	0	0
Standard error[3]	107	0	0	R	45	111	291	182	R	R	R	0	0
Average basal area	94	0	0	15	66	107	113	109	75	86	146	0	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 193.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Prairie Unit, Minnesota, 1977[1]

Elm-ash-cottonwood forest type - Site index class 51-60

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	0	0	0	0	0	0	0	0	0	0	0	0	0
Red pine	0	0	0	0	0	0	0	0	0	0	0	0	0
Jack pine	0	0	0	0	0	0	0	0	0	0	0	0	0
White spruce	0	0	0	0	0	0	0	0	0	0	0	0	0
Black spruce	0	0	0	0	0	0	0	0	0	0	0	0	0
Balsam fir	0	0	0	0	0	0	0	0	0	0	0	0	0
Tamarack	7	71	0	0	0	0	0	0	0	0	0	0	0
Northern white-cedar	0	0	0	0	0	0	0	0	0	0	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	7	71	0	0	0	0	0	0	0	0	0	0	0
Hardwoods:													
Select white oaks	28	0	0	0	0	0	0	0	277	0	0	0	0
Select red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Soft maple	54	0	0	0	0	0	0	0	0	0	0	541	0
Ash	15	62	0	0	0	0	29	0	0	0	0	0	0
Balsam poplar	6	0	0	0	0	60	0	0	0	0	0	0	0
Paper birch	7	65	0	0	0	0	0	0	0	0	0	0	0
Bigtooth aspen	0	0	0	0	0	0	0	0	0	0	0	0	0
Quaking aspen	0	0	0	0	0	0	0	0	0	0	0	0	0
Basswood	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	221	0	0	334	0	0	144	0	239	0	392	420	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	276	0	0	479	0	391	370	0	211	0	194	178	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	606	128	0	813	0	451	543	0	727	0	586	1,139	0
Total all species	613	199	0	813	0	451	543	0	727	0	586	1,139	0
Number of plots	10	1	0	1	0	1	3	0	1	0	2	1	0
Standard error[3]	98	R	0	R	0	R	132	0	R	0	323	R	0
Average basal area	75	23	0	120	0	56	90	0	75	0	54	101	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 194.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Prairie Unit, Minnesota, 1977[1]

Elm-ash-cottonwood forest type - Site index class 61-70

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years) 0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	0	0	0	0	0	0	0	0	0	0	0	0	0
Red pine	0	0	0	0	0	0	0	0	0	0	0	0	0
Jack pine	0	0	0	0	0	0	0	0	0	0	0	0	0
White spruce	0	0	0	0	0	0	0	0	0	0	0	0	0
Black spruce	0	0	0	0	0	0	0	0	0	0	0	0	0
Balsam fir	0	0	0	0	0	0	0	0	0	0	0	0	0
Tamarack	0	0	0	0	0	0	0	0	0	0	0	0	0
Northern white-cedar	0	0	0	0	0	0	0	0	0	0	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	0	0	0	0	0	0	0	0	0	0	0	0	0
Hardwoods:													
Select white oaks	13	0	0	0	0	25	0	0	0	0	0	0	55
Select red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Soft maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	105	0	0	138	191	0	84	129	0	0	311	0	0
Balsam poplar	69	0	0	572	0	24	0	51	0	0	0	0	0
Paper birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Bigtooth aspen	0	0	0	0	0	0	0	0	0	0	0	0	0
Ouaking aspen	51	0	0	0	0	169	0	0	0	0	0	0	0
Basswood	21	0	0	0	0	0	0	80	0	0	0	0	128
Elm	103	0	0	0	50	134	57	0	0	0	0	0	469
Select hardwoods	17	0	0	0	0	14	124	0	0	0	0	0	0
Other hardwoods	615	0	0	303	971	494	732	512	0	0	913	0	270
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	993	0	0	1,012	1,212	860	997	773	0	0	1,224	0	921
Total all species	993	0	0	1,012	1,212	860	997	773	0	0	1,224	0	921
Number of plots	10	0	0	1	2	3	1	1	0	0	1	0	1
Standard error[3]	96	0	0	R	392	213	R	R	0	0	R	0	R
Average basal area	100	0	0	112	132	80	90	79	0	0	105	0	109

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 195.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Prairie Unit, Minnesota, 1977[1]

Elm-ash-cottonwood forest type - All site index classes

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	0	0	0	0	0	0	0	0	0	0	0	0	0
Red pine	0	0	0	0	0	0	0	0	0	0	0	0	0
Jack pine	0	0	0	0	0	0	0	0	0	0	0	0	0
White spruce	0	0	0	0	0	0	0	0	0	0	0	0	0
Black spruce	0	0	0	0	0	0	0	0	0	0	0	0	0
Balsam fir	0	0	0	0	0	0	0	0	0	0	0	0	0
Tamarack	2	71	0	0	0	0	0	0	0	0	0	0	0
Northern white-cedar	0	0	0	0	0	0	0	0	0	0	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	2	71	0	0	0	0	0	0	0	0	0	0	0
Hardwoods:													
Select white oaks	16	0	0	0	0	11	16	11	139	0	0	0	55
Select red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Soft maple	49	0	0	0	0	129	45	0	0	0	0	541	0
Ash	81	62	0	46	198	0	132	89	24	140	78	0	0
Balsam poplar	35	0	0	203	0	19	47	22	0	59	0	0	0
Paper birch	14	65	0	0	0	0	0	24	131	60	0	0	0
Bigtooth aspen	0	0	0	0	0	0	0	0	0	0	0	0	0
Quaking aspen	25	0	0	0	0	119	7	0	0	0	11	0	0
Basswood	12	0	0	0	35	0	12	16	0	0	0	0	128
Elm	133	0	0	111	77	58	133	106	208	184	196	420	469
Select hardwoods	6	0	0	0	0	6	23	0	0	0	0	0	0
Other hardwoods	436	0	0	270	491	661	320	616	105	0	608	178	270
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	807	128	0	630	801	1,003	736	885	607	443	893	1,139	921
Total all species	808	199	0	630	801	1,003	736	885	607	443	893	1,139	921
Number of plots	37	1	0	3	4	7	8	5	2	1	4	1	1
Standard error[3]	83	R	0	288	287	339	106	149	120	R	221	R	R
Average basal area	90	23	0	82	99	95	95	88	75	86	90	101	109

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 196.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Prairie Unit, Minnesota, 1977[1]

Maple-basswood forest type - Site index class 0-50

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years) 0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	0	0	0	0	0	0	0	0	0	0	0	0	0
Red pine	0	0	0	0	0	0	0	0	0	0	0	0	0
Jack pine	0	0	0	0	0	0	0	0	0	0	0	0	0
White spruce	0	0	0	0	0	0	0	0	0	0	0	0	0
Black spruce	0	0	0	0	0	0	0	0	0	0	0	0	0
Balsam fir	0	0	0	0	0	0	0	0	0	0	0	0	0
Tamarack	0	0	0	0	0	0	0	0	0	0	0	0	0
Northern white-cedar	0	0	0	0	0	0	0	0	0	0	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	0	0	0	0	0	0	0	0	0	0	0	0	0
Hardwoods:													
Select white oaks	109	0	0	26	0	0	0	164	225	143	114	0	0
Select red oaks	48	0	0	0	0	0	0	193	20	0	58	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	58	0	0	0	0	0	0	327	0	0	0	0	0
Soft maple	3	0	0	0	0	0	0	0	0	0	18	0	0
Ash	131	0	31	0	0	348	0	119	110	297	76	0	0
Balsam poplar	9	0	0	0	0	24	0	0	33	0	0	0	0
Paper birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Bigtooth aspen	0	0	0	0	0	0	0	0	0	0	0	0	0
Quaking aspen	15	0	0	128	0	0	0	0	0	0	0	0	0
Basswood	44	0	0	0	0	199	0	116	0	0	0	0	0
Elm	306	44	76	198	0	284	0	207	452	105	641	0	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	23	0	0	0	0	55	0	10	11	16	65	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	745	44	107	352	0	910	0	1,135	850	560	972	0	0
Total all species	745	44	107	352	0	910	0	1,135	850	560	972	0	0
Number of plots	17	1	1	2	0	2	0	3	3	2	3	0	0
Standard error[3]	133	R	R	77	0	97	0	574	93	33	358	0	0
Average basal area	88	23	82	64	0	118	0	94	101	81	94	0	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 197.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Prairie Unit, Minnesota, 1977[1]

Maple-basswood forest type - Site index class 51-60

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	0	0	0	0	0	0	0	0	0	0	0	0	0
Red pine	0	0	0	0	0	0	0	0	0	0	0	0	0
Jack pine	0	0	0	0	0	0	0	0	0	0	0	0	0
White spruce	0	0	0	0	0	0	0	0	0	0	0	0	0
Black spruce	0	0	0	0	0	0	0	0	0	0	0	0	0
Balsam fir	0	0	0	0	0	0	0	0	0	0	0	0	0
Tamarack	0	0	0	0	0	0	0	0	0	0	0	0	0
Northern white-cedar	0	0	0	0	0	0	0	0	0	0	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	0	0	0	0	0	0	0	0	0	0	0	0	0
Hardwoods:													
Select white oaks	159	0	0	0	54	0	151	182	234	89	377	60	0
Select red oaks	87	0	0	0	0	0	56	111	0	88	0	221	0
Other red oaks	2	0	0	0	0	0	0	0	0	21	0	0	0
Hickory	3	0	0	0	0	0	0	0	0	0	0	18	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	98	0	0	0	0	0	197	60	99	62	0	85	0
Soft maple	17	0	0	0	109	0	0	0	0	0	0	71	0
Ash	85	0	0	0	181	0	27	106	72	72	215	85	0
Balsam poplar	0	0	0	0	0	0	0	0	0	0	0	0	0
Paper birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Bigtooth aspen	0	0	0	0	0	0	0	0	0	0	0	0	0
Quaking aspen	31	0	0	0	245	0	49	0	12	0	120	0	0
Basswood	337	0	0	0	0	0	272	247	381	451	143	577	0
Elm	297	0	0	0	131	0	169	391	259	151	122	583	0
Select hardwoods	4	0	0	0	0	0	18	0	0	0	0	0	0
Other hardwoods	36	0	0	0	38	0	115	5	0	12	0	21	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	1,156	0	0	0	759	0	1,054	1,102	1,057	945	977	1,720	0
Total all species	1,156	0	0	0	759	0	1,054	1,102	1,057	945	977	1,720	0
Number of plots	28	0	0	0	1	0	7	6	4	3	2	5	0
Standard error[3]	96	0	0	0	R	0	181	174	70	249	342	317	0
Average basal area	102	0	0	0	120	0	96	98	101	86	100	120	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 198.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Prairie Unit, Minnesota, 1977[1]

Maple-basswood forest type - Site index class 61-70

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)										
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	0	0	0	0	0	0	0	0	0	0	0	0	0
Red pine	0	0	0	0	0	0	0	0	0	0	0	0	0
Jack pine	0	0	0	0	0	0	0	0	0	0	0	0	0
White spruce	0	0	0	0	0	0	0	0	0	0	0	0	0
Black spruce	0	0	0	0	0	0	0	0	0	0	0	0	0
Balsam fir	0	0	0	0	0	0	0	0	0	0	0	0	0
Tamarack	0	0	0	0	0	0	0	0	0	0	0	0	0
Northern white-cedar	0	0	0	0	0	0	0	0	0	0	0	0	0
Other softwoods	3	0	0	0	0	0	17	0	0	0	0	0	0
Total	3	0	0	0	0	0	17	0	0	0	0	0	0
Hardwoods:													
Select white oaks	82	0	0	0	0	157	137	158	14	67	0	0	0
Select red oaks	57	0	115	0	0	0	25	64	182	0	0	0	79
Other red oaks	8	0	206	0	0	0	0	0	0	0	0	0	0
Hickory	1	0	0	0	0	0	0	3	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	74	0	0	0	0	0	60	92	187	0	0	0	241
Soft maple	3	0	0	0	0	0	0	0	11	13	0	0	0
Ash	94	0	0	0	0	0	151	126	146	34	151	0	0
Balsam poplar	12	0	0	0	0	292	0	0	0	0	0	0	0
Paper birch	11	0	0	0	0	0	0	0	18	68	0	0	0
Bigtooth aspen	2	0	41	0	0	0	0	0	0	0	0	0	0
Quaking aspen	17	0	0	0	0	0	83	0	0	0	0	0	0
Basswood	174	0	63	0	0	0	223	97	327	349	0	117	0
Elm	489	0	73	283	0	576	183	457	386	699	1,528	989	480
Select hardwoods	13	0	0	0	0	0	0	45	0	20	0	0	0
Other hardwoods	85	0	28	0	0	227	31	106	139	140	67	22	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	1,121	0	526	283	0	1,252	894	1,148	1,410	1,389	1,746	1,128	800
Total all species	1,124	0	526	283	0	1,252	911	1,148	1,410	1,389	1,746	1,128	800
Number of plots	25	0	1	1	0	1	5	6	4	3	1	2	1
Standard error[3]	86	0	R	R	0	R	227	112	78	317	R	162	R
Average basal area	93	0	79	30	0	154	82	93	110	101	101	79	101

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 199.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Prairie Unit, Minnesota, 1977[1]

Maple-basswood forest type - Site index class 71-80

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)										
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	0	0	0	0	0	0	0	0	0	0	0	0	0
Red pine	0	0	0	0	0	0	0	0	0	0	0	0	0
Jack pine	0	0	0	0	0	0	0	0	0	0	0	0	0
White spruce	0	0	0	0	0	0	0	0	0	0	0	0	0
Black spruce	0	0	0	0	0	0	0	0	0	0	0	0	0
Balsam fir	0	0	0	0	0	0	0	0	0	0	0	0	0
Tamarack	0	0	0	0	0	0	0	0	0	0	0	0	0
Northern white-cedar	0	0	0	0	0	0	0	0	0	0	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	0	0	0	0	0	0	0	0	0	0	0	0	0
Hardwoods:													
Select white oaks	153	0	45	0	0	0	514	150	28	0	695	0	0
Select red oaks	22	0	0	0	0	0	0	0	89	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	53	0	28	0	0	0	0	0	192	0	0	0	0
Soft maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	159	0	30	127	0	427	124	141	194	0	163	0	0
Balsam poplar	0	0	0	0	0	0	0	0	0	0	0	0	0
Paper birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Bigtooth aspen	0	0	0	0	0	0	0	0	0	0	0	0	0
Quaking aspen	25	0	0	302	0	0	0	0	0	0	0	0	0
Basswood	307	0	0	0	0	0	89	799	300	0	301	0	0
Elm	454	0	140	231	0	563	259	584	612	0	528	0	0
Select hardwoods	5	0	0	0	0	0	0	21	0	0	0	0	0
Other hardwoods	58	0	52	111	0	207	0	90	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	1,236	0	295	771	0	1,197	986	1,785	1,414	0	1,687	0	0
Total all species	1,236	0	295	771	0	1,197	986	1,785	1,414	0	1,687	0	0
Number of plots	12	0	2	1	0	1	1	3	3	0	1	0	0
Standard error[3]	198	0	145	R	0	R	R	455	331	0	R	0	0
Average basal area	90	0	64	41	0	82	79	106	86	0	169	0	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 200.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Prairie Unit, Minnesota, 1977[1]

Maple-basswood forest type - All site index classes

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)										
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	0	0	0	0	0	0	0	0	0	0	0	0	0
Red pine	0	0	0	0	0	0	0	0	0	0	0	0	0
Jack pine	0	0	0	0	0	0	0	0	0	0	0	0	0
White spruce	0	0	0	0	0	0	0	0	0	0	0	0	0
Black spruce	0	0	0	0	0	0	0	0	0	0	0	0	0
Balsam fir	0	0	0	0	0	0	0	0	0	0	0	0	0
Tamarack	0	0	0	0	0	0	0	0	0	0	0	0	0
Northern white-cedar	0	0	0	0	0	0	0	0	0	0	0	0	0
Other softwoods	1	0	0	0	0	0	7	0	0	0	0	0	0
Total	1	0	0	0	0	0	7	0	0	0	0	0	0
Hardwoods:													
Select white oaks	123	0	22	13	54	39	174	166	117	94	256	43	0
Select red oaks	60	0	29	0	0	0	40	90	70	33	25	158	79
Other red oaks	3	0	52	0	0	0	0	0	0	8	0	0	0
Hickory	1	0	0	0	0	0	0	1	0	0	0	13	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	77	0	14	0	0	0	129	105	129	23	0	61	241
Soft maple	7	0	0	0	109	0	0	0	3	5	8	50	0
Ash	107	0	23	32	181	281	82	121	119	114	139	60	0
Balsam poplar	5	0	0	0	0	85	0	0	7	0	0	0	0
Paper birch	3	0	0	0	0	0	0	0	5	25	0	0	0
Bigtooth aspen	1	0	10	0	0	0	0	0	0	0	0	0	0
Quaking aspen	22	0	0	140	245	0	58	0	3	0	34	0	0
Basswood	222	0	16	0	0	100	239	267	262	300	84	446	0
Elm	378	44	107	228	131	427	181	414	398	345	603	699	480
Select hardwoods	6	0	0	0	0	0	9	19	0	7	0	0	0
Other hardwoods	51	0	33	28	38	136	74	54	39	61	37	21	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	1,066	44	305	439	759	1,067	987	1,237	1,151	1,016	1,186	1,551	800
Total all species	1,067	44	305	439	759	1,067	994	1,237	1,151	1,016	1,186	1,551	800
Number of plots	83	1	4	4	1	4	13	18	15	8	7	7	1
Standard error[3]	60	R	104	116	R	100	126	135	96	181	207	247	R
Average basal area	94	23	72	50	120	118	90	97	98	91	107	108	101

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 201.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Prairie Unit, Minnesota, 1977[1]

Aspen forest type - Site index class 0-50

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years) 0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	0	0	0	0	0	0	0	0	0	0	0	0	0
Red pine	0	0	0	0	0	0	0	0	0	0	0	0	0
Jack pine	0	0	0	0	0	0	0	0	0	0	0	0	0
White spruce	1	0	0	0	0	0	9	0	0	0	0	0	0
Black spruce	0	0	0	0	0	0	0	0	0	0	0	0	0
Balsam fir	0	0	0	0	0	0	0	0	0	0	0	0	0
Tamarack	3	0	0	0	0	0	23	0	0	0	0	0	0
Northern white-cedar	0	0	0	0	0	0	0	0	0	0	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	4	0	0	0	0	0	32	0	0	0	0	0	0
Hardwoods:													
Select white oaks	32	7	8	0	0	11	68	98	58	369	0	0	0
Select red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Soft maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	7	5	0	0	0	0	0	0	267	0	0	0	0
Balsam poplar	38	11	16	0	33	101	94	12	0	0	0	0	0
Paper birch	3	0	0	0	0	0	0	0	148	0	0	0	0
Bigtooth aspen	0	0	0	0	0	0	0	0	0	0	0	0	0
Quaking aspen	224	72	172	132	227	420	360	286	463	40	0	0	0
Basswood	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	0	0	0	0	0	0	0	0	0	0	0	0	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	2	0	0	0	0	0	0	0	0	101	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	308	94	196	132	260	532	523	396	936	510	0	0	0
Total all species	311	94	196	132	260	532	554	396	936	510	0	0	0
Number of plots	44	13	9	1	2	8	5	4	1	1	0	0	0
Standard error[3]	45	33	36	R	42	146	146	61	R	R	0	0	0
Average basal area	53	29	47	38	55	64	80	67	116	101	0	0	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 202.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Prairie Unit, Minnesota, 1977[1]

Aspen forest type - Site index class 51-60

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	0	0	0	0	0	0	0	0	0	0	0	0	0
Red pine	0	0	0	0	0	0	0	0	0	0	0	0	0
Jack pine	0	0	0	0	0	0	0	0	0	0	0	0	0
White spruce	3	0	9	0	5	0	0	0	0	0	0	0	0
Black spruce	0	0	0	0	0	0	0	0	0	0	0	0	0
Balsam fir	2	0	8	0	0	0	0	0	0	0	0	0	0
Tamarack	0	0	0	0	0	0	0	0	0	0	0	0	0
Northern white-cedar	0	0	0	0	0	0	0	0	0	0	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	5	0	17	0	5	0	0	0	0	0	0	0	0
Hardwoods:													
Select white oaks	26	4	23	32	18	23	56	231	0	0	0	0	0
Select red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Soft maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	8	0	4	0	4	0	0	234	0	0	0	0	0
Balsam poplar	57	36	21	21	50	150	142	154	0	0	0	0	0
Paper birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Bigtooth aspen	0	0	0	0	0	0	0	0	0	0	0	0	0
Quaking aspen	279	161	187	90	387	553	286	687	0	0	0	0	0
Basswood	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	6	10	0	0	0	20	0	21	0	0	0	0	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	7	0	4	0	25	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	382	212	239	142	485	746	483	1,327	0	0	0	0	0
Total all species	387	212	256	142	489	746	483	1,327	0	0	0	0	0
Number of plots	73	19	16	7	16	9	4	2	0	0	0	0	0
Standard error	44	56	49	29	95	118	21	588	0	0	0	0	0
Average basal area	56	36	52	39	69	78	59	119	0	0	0	0	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

Table 203.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Prairie Unit, Minnesota, 1977[1]

Aspen forest type - Site index class 61-70

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years) 0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	0	0	0	0	0	0	0	0	0	0	0	0	0
Red pine	9	0	0	0	0	37	0	0	0	0	0	0	0
Jack pine	5	0	0	0	0	22	0	0	0	0	0	0	0
White spruce	0	0	0	0	0	0	0	0	0	0	0	0	0
Black spruce	0	0	0	0	0	0	0	0	0	0	0	0	0
Balsam fir	0	0	0	0	0	0	0	0	0	0	0	0	0
Tamarack	0	0	0	0	0	0	0	0	0	0	0	0	0
Northern white-cedar	0	0	0	0	0	0	0	0	0	0	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	14	0	0	0	0	59	0	0	0	0	0	0	0
Hardwoods:													
Select white oaks	99	37	0	39	119	169	234	0	0	0	0	0	0
Select red oaks	6	0	0	0	22	0	0	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Soft maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	8	8	0	0	17	4	0	0	0	0	0	0	0
Balsam poplar	44	16	0	58	26	88	95	0	0	0	0	0	0
Paper birch	9	21	0	0	0	15	0	0	0	0	0	0	0
Bigtooth aspen	0	0	0	0	0	0	0	0	0	0	0	0	0
Quaking aspen	428	174	217	445	547	564	586	0	0	0	0	0	0
Basswood	6	0	0	0	15	6	0	0	0	0	0	0	0
Elm	8	13	0	0	7	6	29	0	0	0	0	0	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	7	0	0	16	2	18	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	613	268	217	558	754	870	945	0	0	0	0	0	0
Total all species	627	268	217	558	754	929	945	0	0	0	0	0	0
Number of plots	42	10	3	5	12	10	2	0	0	0	0	0	0
Standard error	63	54	36	36	115	135	26	0	0	0	0	0	0
Average basal area	69	46	53	59	75	89	105	0	0	0	0	0	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

Table 204.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Prairie Unit, Minnesota, 1977[1]

Aspen forest type - Site index class 71-80

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years) 0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	0	0	0	0	0	0	0	0	0	0	0	0	0
Red pine	0	0	0	0	0	0	0	0	0	0	0	0	0
Jack pine	0	0	0	0	0	0	0	0	0	0	0	0	0
White spruce	0	0	0	0	0	0	0	0	0	0	0	0	0
Black spruce	0	0	0	0	0	0	0	0	0	0	0	0	0
Balsam fir	0	0	0	0	0	0	0	0	0	0	0	0	0
Tamarack	0	0	0	0	0	0	0	0	0	0	0	0	0
Northern white-cedar	0	0	0	0	0	0	0	0	0	0	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	0	0	0	0	0	0	0	0	0	0	0	0	0
Hardwoods:													
Select white oaks	44	0	0	55	142	0	0	0	0	0	0	0	0
Select red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Soft maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	49	0	0	0	103	71	80	0	0	0	0	0	0
Balsam poplar	99	0	25	127	87	133	209	0	0	0	0	0	0
Paper birch	26	0	0	0	0	76	81	0	0	0	0	0	0
Bigtooth aspen	0	0	0	0	0	0	0	0	0	0	0	0	0
Quaking aspen	745	0	230	702	874	1,131	538	0	0	0	0	0	0
Basswood	3	0	0	0	0	10	0	0	0	0	0	0	0
Elm	13	0	12	0	15	22	0	0	0	0	0	0	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	2	0	0	0	0	8	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	981	0	267	885	1,221	1,451	909	0	0	0	0	0	0
Total all species	981	0	267	885	1,221	1,451	909	0	0	0	0	0	0
Number of plots	21	0	5	4	5	6	1	0	0	0	0	0	0
Standard error[3]	124	0	71	187	201	180	R	0	0	0	0	0	0
Average basal area	87	0	54	92	93	107	79	0	0	0	0	0	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 205.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Prairie Unit, Minnesota, 1977[1]

Aspen forest type - All site index classes

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	0	0	0	0	0	0	0	0	0	0	0	0	0
Red pine	2	0	0	0	0	11	0	0	0	0	0	0	0
Jack pine	1	0	0	0	0	7	0	0	0	0	0	0	0
White spruce	1	0	4	0	2	0	4	0	0	0	0	0	0
Black spruce	0	0	0	0	0	0	0	0	0	0	0	0	0
Balsam fir	1	0	4	0	0	0	0	0	0	0	0	0	0
Tamarack	1	0	0	0	0	0	9	0	0	0	0	0	0
Northern white-cedar	0	0	0	0	0	0	0	0	0	0	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	6	0	8	0	2	18	13	0	0	0	0	0	0
Hardwoods:													
Select white oaks	46	13	14	38	69	60	86	142	58	369	0	0	0
Select red oaks	1	0	0	0	7	0	0	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Soft maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	13	3	2	0	22	14	7	78	267	0	0	0	0
Balsam poplar	54	24	18	55	46	116	120	59	0	0	0	0	0
Paper birch	6	5	0	0	0	18	7	0	148	0	0	0	0
Bigtooth aspen	0	0	0	0	0	0	0	0	0	0	0	0	0
Quaking aspen	355	137	192	341	502	629	388	420	463	40	0	0	0
Basswood	2	0	0	0	5	3	0	0	0	0	0	0	0
Elm	6	7	2	0	5	11	5	7	0	0	0	0	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	5	0	2	5	12	7	0	0	0	101	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	488	189	230	439	670	860	612	706	936	510	0	0	0
Total all species	494	189	238	439	672	877	625	706	936	510	0	0	0
Number of plots	180	42	33	17	35	33	12	6	1	1	0	0	0
Standard error[3]	33	31	27	87	78	87	79	251	R	R	0	0	0
Average basal area	62	36	51	57	74	83	77	84	116	101	0	0	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 206.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Prairie Unit, Minnesota, 1977[1]

Balsam poplar forest type - Site index class 0-50

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years) 0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	0	0	0	0	0	0	0	0	0	0	0	0	0
Red pine	0	0	0	0	0	0	0	0	0	0	0	0	0
Jack pine	0	0	0	0	0	0	0	0	0	0	0	0	0
White spruce	0	0	0	0	0	0	0	0	0	0	0	0	0
Black spruce	0	0	0	0	0	0	0	0	0	0	0	0	0
Balsam fir	0	0	0	0	0	0	0	0	0	0	0	0	0
Tamarack	0	0	0	0	0	0	0	0	0	0	0	0	0
Northern white-cedar	0	0	0	0	0	0	0	0	0	0	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	0	0	0	0	0	0	0	0	0	0	0	0	0
Hardwoods:													
Select white oaks	4	0	0	0	12	0	0	0	0	0	0	0	0
Select red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Soft maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	0	0	0	0	0	0	0	0	0	0	0	0	0
Balsam poplar	253	386	63	0	300	353	0	0	0	0	0	0	0
Paper birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Bigtooth aspen	0	0	0	0	0	0	0	0	0	0	0	0	0
Quaking aspen	41	0	0	0	73	65	0	0	0	0	0	0	0
Basswood	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	0	0	0	0	0	0	0	0	0	0	0	0	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	6	0	22	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	305	386	84	0	385	418	0	0	0	0	0	0	0
Total all species	305	386	84	0	385	418	0	0	0	0	0	0	0
Number of plots	10	1	3	0	3	3	0	0	0	0	0	0	0
Standard error[3]	81	R	55	0	200	144	0	0	0	0	0	0	0
Average basal area	41	41	24	0	45	52	0	0	0	0	0	0	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 207.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Prairie Unit, Minnesota, 1977[1]

Balsam poplar forest type - Site index class 51-60

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	0	0	0	0	0	0	0	0	0	0	0	0	0
Red pine	0	0	0	0	0	0	0	0	0	0	0	0	0
Jack pine	0	0	0	0	0	0	0	0	0	0	0	0	0
White spruce	0	0	0	0	0	0	0	0	0	0	0	0	0
Black spruce	0	0	0	0	0	0	0	0	0	0	0	0	0
Balsam fir	0	0	0	0	0	0	0	0	0	0	0	0	0
Tamarack	0	0	0	0	0	0	0	0	0	0	0	0	0
Northern white-cedar	0	0	0	0	0	0	0	0	0	0	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	0	0	0	0	0	0	0	0	0	0	0	0	0
Hardwoods:													
Select white oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Select red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Soft maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	55	0	0	0	0	220	0	0	0	0	0	0	0
Balsam poplar	298	208	0	0	192	580	218	0	0	0	0	0	0
Paper birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Bigtooth aspen	0	0	0	0	0	0	0	0	0	0	0	0	0
Quaking aspen	48	46	0	0	72	50	0	0	0	0	0	0	0
Basswood	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	46	0	0	0	105	0	158	0	0	0	0	0	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	9	0	0	0	17	0	37	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	456	254	0	0	386	850	412	0	0	0	0	0	0
Total all species	456	254	0	0	386	850	412	0	0	0	0	0	0
Number of plots	8	3	0	0	2	2	1	0	0	0	0	0	0
Standard error[3]	105	118	0	0	53	202	R	0	0	0	0	0	0
Average basal area	54	34	0	0	68	73	49	0	0	0	0	0	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

Table 208.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Prairie Unit, Minnesota, 1977[1]

Balsam poplar forest type - All site index classes

(In cubic feet per acre)

Species	Average[2]	Stand-age class (years) 0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	0	0	0	0	0	0	0	0	0	0	0	0	0
Red pine	0	0	0	0	0	0	0	0	0	0	0	0	0
Jack pine	0	0	0	0	0	0	0	0	0	0	0	0	0
White spruce	0	0	0	0	0	0	0	0	0	0	0	0	0
Black spruce	0	0	0	0	0	0	0	0	0	0	0	0	0
Balsam fir	0	0	0	0	0	0	0	0	0	0	0	0	0
Tamarack	0	0	0	0	0	0	0	0	0	0	0	0	0
Northern white-cedar	0	0	0	0	0	0	0	0	0	0	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	0	0	0	0	0	0	0	0	0	0	0	0	0
Hardwoods:													
Select white oaks	2	0	0	0	6	0	0	0	0	0	0	0	0
Select red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Soft maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	25	0	0	55	0	88	0	0	0	0	0	0	0
Balsam poplar	308	253	63	247	310	444	218	779	0	0	0	0	0
Paper birch	3	0	0	28	0	0	0	0	0	0	0	0	0
Bigtooth aspen	0	0	0	0	0	0	0	0	0	0	0	0	0
Quaking aspen	53	34	0	0	78	59	0	268	0	0	0	0	0
Basswood	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	33	0	0	24	35	0	158	304	0	0	0	0	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	6	0	22	0	6	0	37	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	429	287	84	354	435	591	412	1,352	0	0	0	0	0
Total all species	429	287	84	354	435	591	412	1,352	0	0	0	0	0
Number of plots	22	4	3	2	6	5	1	1	0	0	0	0	0
Standard error[3]	71	90	55	79	103	147	R	R	0	0	0	0	0
Average basal area	51	36	24	45	58	61	49	109	0	0	0	0	0

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3] R indicates that there was an insufficient number of plots to compute the standard error.

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Hahn, Jerold T., and Gerhard K. Raile.

1982. Empirical yield tables for Minnesota. U.S. Department of Agriculture Forest Service, General Technical Report NC-71, 212 p. U.S. Department of Agriculture Forest Service, North Central Forest Experiment Station, St. Paul, Minnesota.

Describes the tables derived from the 1977 Forest Survey of Minnesota and presents examples of how the tables can be used. These tables are broken down according to Minnesota's four Forest Survey Units, 14 forest types, and 5 site index classes. Presents 210 of the 350 possible tables that contained sufficient data to justify publication.

KEY WORDS: Inventory, volume, growth.

United States Department of Agriculture

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General Technical Report **NC-72**

Wildland Fire Management Economics: A State of the Art Review and Bibliography

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and Albert J. Simard

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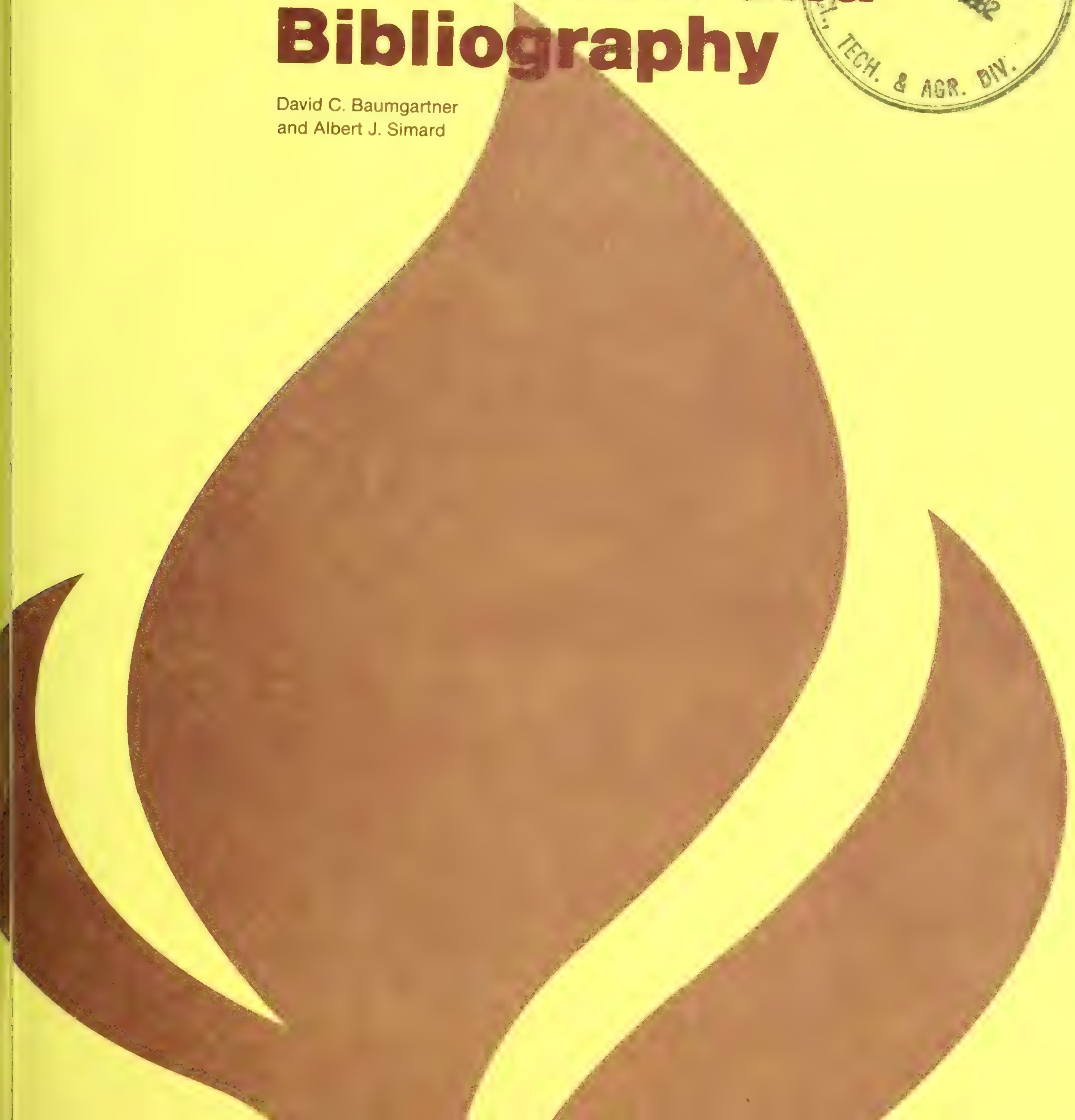

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WILDLAND FIRE MANAGEMENT ECONOMICS: A STATE OF THE ART REVIEW AND BIBLIOGRAPHY

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Past wildfire management strategies have neglected the fact that wildfire may have beneficial as well as undesirable effects and that fire management should be viewed, not in isolation, but within the context of overall land management objectives (Barney 1975, Lotan 1979). As a result, management strategies were framed with the objective of minimizing the time required to control fires, the number of fires, the size of fires, or the acreage burned. Scant attention was paid to the economic consequences of these strategies.

However, more and more fire management agencies are now being asked to justify the usefulness of their programs in terms of economic efficiency and to fully recognize the potential beneficial effects of some fires as well as the necessity to view fire management as an integral part of land management. Attempts have been made to determine: appropriate fire management budgets; proper allocation of expenditures between various fire management functions; and costs, damages, and benefits of wildland fire and fire management programs.

The objective of this review and interpretation of the literature pertaining to fire economics is to provide essential background information for selecting, developing, and applying appropriate techniques for evaluating fire management programs.

METHODS

The bibliography includes references concerned with applying economic techniques to solve wildland fire management problems. It was compiled from an extensive search of a wide variety of sources. Some citations were obtained locally, either from the USDA Forest Service North Central Forest Experiment Station Fire Management Project files or the Michigan State University library. Others were obtained from bibliographic data bases such as FIREBASE and the DIALOG service of Lockheed Information Services, which includes AGRICOLA (Bibliography of Agriculture). Generous support was obtained from USDA Forest Service and university researchers with past or current interest in wildland fire economics. Additional citations and information were obtained from key USDA Forest Service Cooperative Fire Protection, Research, and National Forest System staffs. State foresters and other Federal land management agencies were contacted by letter and asked to contribute relevant materials and we received a reply from fire management agencies from 26 States.

Even given the effort described above, the bibliography is not exhaustive. However, we feel it represents the directly relevant literature, particularly since 1960, and accurately describes the current state of the art in wildfire economics.

Annotations and key words are provided for a majority of the references. They are, however, omitted if a copy of the document or abstract could not be obtained or if the title seemed to adequately describe the content of the material. Several books that provide good general background in wildland fire management or in resource economics are listed separately at the end of the bibliography.

One or more of the following criteria were used for including references:

(1) The reference provided an example of how existing economic theory might be applied to fire management.

(2) The reference described a practical example of the use of economics in wildland fire management using real data.

(3) The reference reflected the use of economics in past or current research and/or policy direction of the USDA Forest Service or other fire management agency.

(4) The reference contained a useful bibliography of related material and/or synthesized a large volume of loosely connected information.

(5) The reference was current or its message had retained importance in essentially unchanged form.

ECONOMIC THEORY

Gorte and Gorte (1979) explore the history and evolution of economics as applied to fire management, particularly the cost-plus-loss concept. They trace the development of this concept beginning with the work of Sparhawk (1925) and Flint (1928) who were among the first to develop least-cost-plus-loss models. Next, they reviewed the work of Hornby (1936) who used acreage burned rather than presuppression expenditure as the independent variable. They then discussed the research of Headley (1943) who provided "the first attempt at a thorough analysis of fire control policy alternative."

The work of Craig *et al.* (1945) who recognized the need for marginal analysis is described as are the findings of Arnold (1949) who developed a model to derive suppression-cost-plus-damage for a number of presuppression levels measured by attack time, and Mactavish (1965) who worked with an expanded version of Arnold's model. Parks' (1964) model, which was "analogous to the first step of Arnold's model," is noted as is the work of Davis (1971) who explicitly recognized some limitations of the least-cost-plus-loss models. Finally, they describe the work of Simard (1976) who augmented the cost-plus-loss concept by equating the ratios of marginal factor costs to marginal value products among the various fire management inputs. He also explicitly recognized the possible beneficial effects of fire using the same analytical technique.

Mills (1979, 1980) also explicitly recognizes the possibility of beneficial wildfire effects noting that the "cost-plus-loss" concept would be more properly labeled "cost-plus-net value change." He also correctly points out that minimizing "cost-plus-net value change" leads to the same program selection as maximizing financial return expressed as present net worth. Similarly, the last program increment added before reaching the minimum has a benefit-cost ratio of 1.0 and an internal rate of return equal to the next best alternative rate. Gorte and Gorte (1979) describe the work of several researchers (O'Connell 1971, Zivnuska 1972, Jischke and Shamblin 1974) who have used variations of benefit-cost analysis in analyzing fire management economics. Nautiyal and Doan (1974) used an indifference approach with which a manager can trade harvested acres for burned acres and offset protection costs with timber sale receipts.

All in all, the economic theory of fire management is compatible with basic applied production, or microeconomic theory, and is well accepted. Some models needed to determine the economic efficiency of some components of fire management programs are available and others are being developed. The "cost" component needed as input for the models is reasonably easy to obtain with good bookkeeping. The basic difficulty lies in determining and predicting losses and benefits, or the net value changes wildfires have caused or are likely to cause. These crucial elements for any of the economic models cited above are virtually impossible to determine precisely. Even for timber, the questions of what the appropriate discount rate should be for future market values or what the future value will be, are unresolved. Nonmarket values and off-site values are even more difficult to determine precisely.

VALUE-AT-RISK AND APPRAISAL OF NET VALUE CHANGE

It has been recognized that past fire damage appraisal systems have not been adequate to serve the needs of the basic theoretical economic fire management models. Economic studies to determine an "adequate level" of fire protection or "justifiable expenditures" were undertaken by Davis (1965), Vogenberger *et al.* (1957), Miller (1968) and Arnold (1949). All emphasized the difficulty inherent in measuring the value changes caused by fires and prefire values that could be affected by fire. All finally resorted to limiting their analysis to a few of the more measurable market values or to including subjective approximations for some values to at least show how their models might work. Noste and Davis (1975) demonstrated the inconsistencies in appraisal techniques by comparing appraisals by the USDA Forest Service and the Bureau of Land Management following two large fires.

Wildfire value change appraisal has been receiving increasing attention. Crosby (1977) developed a general guide for appraising wildfire damages, benefits, and resource values protected. Marty (1979) developed an economic valuation system for fire management planning on the National Forests. Gorte (1979) is completing a new system that permits more accurate appraisal of wildland fire damage in Wisconsin. This system recognizes that some fire effects are beneficial and carefully considers nontimber values. Lewis *et al.* (1979) are studying the "values-at-risk" from wildfire in Alabama.

APPLICATION

Although the solution of prefire value and postfire value change problems is incomplete, several recent studies have attempted to apply the best information available in benefit-cost or cost-plus-loss economic models. Winkworth *et al.* (1979) are conducting a benefit-cost analysis of progress in forest fire protection in North Carolina while Carmichael *et al.* (1979) have completed a benefit-cost study in California. Schweitzer *et al.* (1980) evaluated four levels of initial action and aviation program input using the FOCUS simulation model (Flatman and Storey 1979).

Researchers and policy directors in the USDA Forest Service have recognized the need for better economic information on fire management program alternatives. A policy analysis staff report (Gale 1977) included the following recommendations:

I. Develop new fire management policies that provide a broader, more positive approach to fire.

II. Establish procedures for determining reliable esitmates of forest values.

III. Develop an integrated fire management planning process.

IV. Improve the accounting and budgeting systems of fire management.

V. Develop and implement a comprehensive evaluation system.

Item I. was largely accomplished in February 1978 when a revised fire management policy became effective stating: the basic fire management policy on National Forest System land is to provide well planned and executed fire protection and fire use programs that are cost-effective, responsive to land and resource management goals and objectives, and supportive of the 1974 Forest and Rangeland Renewable Resources Planning Act resource outputs. Efforts to accomplish recommendations II., III., and V. are reflected in the work of Schweitzer *et al.* (1980) entitled "A partial efficiency analysis of the fire management program on six National Forests." This work will be discussed in greater detail because it represents very well the state of the art in evaluating the economic efficiency of USDA Forest Service fire management programs.

Schweitzer *et al.* (1980) evaluated the economic efficiency of the initial attack and aviation component of the fire management program on six widely spaced National Forests using a marginal analysis format. Minimizing the program cost plus the net change in the value of response outputs and structures was the economic efficiency criterion. Four program levels were evaluated. The results of this study included the following:

(1) "The lowest program tested was the most efficient in the majority of the simulated fire years, 12 out of 17 years."

(2) "The most efficient initial attack and aviation program level was not affected by the severity of the fire year in four of the six case study forests."

(3) "The simulated fire suppression cost drops in response to increases in the initial attack and aviation program levels in all case studies."

(4) "The net value change of resource outputs and structures caused by fires was a very small percentage of the total cost + net value change in 13 of the 17 years studied."

(5) "The vast majority of the net value change in these cases was the loss of commercial timber and structures."

The authors also document the limitations of this study that must be overcome before a complete economic analysis of alternative fire management programs can be conducted. Included are:

(1) "Effectiveness estimates of program alternatives and mixes for all five major components of the fire management program (prevention, detection, initial attack, escaped fire suppression, and fuel treatments) must be incorporated within a single model construct."

(2) "The range of the program levels tested should be wider than the 1979 −20 percent to 1979 + 40 percent tested in this study to ensure that the minimum cost + net value change is located."

(3) "The stochastic element must be more completely incorporated throughout the entire analysis from its source in fire occurrence and fire weather variations through to a probability

distribution of resource impacts and cost + net value change itself."

(4) "Even though the preliminary sensitivity analysis in this study demonstrated that errors in the fire effects and resource value estimates would not materially affect the answers on economic efficiency, the accuracy of some of these estimates is still quite suspect."

This study demonstrates that economic efficiency analysis for wildland fire management can be practically applied. At the present time it can indicate general management guidelines using the best resource value figures and prediction techniques available. As these improve, more specific guidelines can be developed. The sensitivity analysis provides important clues as to which resource value and value change variables are most crucial in their influence on the analysis. Research is currently underway (e.g., Althaus 1980, Mills 1980, Simard *et al.* (1980) that should improve resource value, value change, and value-at-risk information including nonmarket, secondary, and off-site values.

The few economic studies of State fire management programs have indicated that past and current fire protection programs have been cost effective and that additional investments in these programs are justified. For example, Winkworth *et al.* (1979) concluded "with every passing year, the timber values at risk in North Carolina are growing, not only due to the success of public incentive programs but as a result of real price increases for standing timber. Using economic guidelines,greater expenditures for fire protection are justified (moreover they are essential) when values at risk increase . . . . North Carolina has not yet reached the point of diminishing returns in wildfire protection." The preceding results are in contrast to those obtained for National Forests, which often indicated that the lowest fire protection level examined was the most cost effective. The contrasting results are not necessarily inconsistent because the fire management programs examined for the National Forests are much more intensive and thus more likely to have reached a point of diminishing returns.

EQUITY

The state of the art in applying economic principles to wildfire management programs appears to be sufficiently developed to provide general guidelines and evaluations. Current research holds the promise of improving the state of knowledge and providing more specific results. Unfortunately, however, this is true only for evaluating economic efficiency. Further, much of the efficiency analysis has focused on the needs of Federal land managers, particularly the USDA Forest Service, in western States containing large acreages of National Forests. In this case it seems reasonable that the costs and benefits of public wildland fire management should be examined from a societal viewpoint because public land management plans and objectives are clearly intended to serve the public interest.

The use of economic analysis to examine the equity of wildfire management programs either separately or in combination with efficiency analysis has been limited. The question of equity is much more important when developing an economic rationale to evaluate programs for managing wildfire on State and private land. To indicate the costs and benefits associated with wildland fire management and assume that they accrue to some vaguely defined unit called "society" is insufficient. Equity analysis is necessary to determine who pays (or should pay) the costs or who reaps the benefits of wildfire management programs. Specific questions that must be addressed were posed in a State and Private Forestry status report on Cooperative Fire Protection Economic Analysis at a USDA Forest Service Regional Foresters and Directors meeting in Missoula in July 1980. They are:

(1) "What level of fire protection and cost is most appropriate and commensurate with management objectives and investments for land protected by States?"

(2) "For lands protected by States, who has interest and derives benefits from fire protection efforts and costs?"

(3) "What protection level and cost is required to protect national interest in the lands protected by States?"

(4) "Who should pay the cost of fire protection and why?"

Harden (1980) addressed the first question. He attempted to measure the cost effectiveness of potential increases and decreases in a State fire protection budget using information developed in the National Forest System's Fiscal Year 1980 Budget Analysis for the Mark Twain National Forest in Missouri. He extrapolated this information to State and private land in Missouri and obtained additional data from the Missouri Department of Conservation to estimate the cost effectiveness. He concluded that reducing suppression expenditures could result in large increases in timber damage and that increasing such expenditures would be cost effective in eastern Missouri and marginally cost effective in western Missouri. This approach gives a partial answer to question (1) but it is still primarily concerned with economic efficiency rather than equity. Questions (2), (3), and (4) involve equity and remain largely unanswered.

Only a few studies have dealt with the question of equity in fire management programs in conjunction with economic efficiency. Kling (1951) and Swager *et al.* (1958) analyzed the cooperative forest fire program. Kling was primarily concerned with a nonquantitative description and evaluation of policy and administrative programs. Swager *et al.* attempted to determine appropriate funding levels for adequate fire protection on non-Federal forest land and how the costs should be shared by Federal, State, and private parties. Although this research provides a gross estimate of equity for sharing costs between Federal and State governments and private sources, it does not indicate how Federal funds should be distributed among States or how States should distribute costs and benefits internally.

We did not locate any references since the work of Swager *et al.* (1958) that dealt explicitly with the question of equity in wildland fire management programs. Although we could have missed some, a decided gap in the state of the art of fire economics is clearly indicated. This is surprising, because questions of equity would appear to be addressable. Relevant data should be available, although somewhat tedious to collect, and conventional welfare economics and public finance theory should be applicable.

SUMMARY

In terms of economic efficiency, the state of the art for using economics in wildland fire management has made significant advances. Partial economic efficiency models have been developed, are being applied, and are capable of providing general guidelines for some aspects of public wildland and fire management. Further advances are likely, such as the development of more complete economic models as well as improved resource value, value change, and value-at-risk information. Recent work by Schweitzer *et al.* (1980) and its expansion in the 1980 Budget Analysis (U.S. Department of Agriculture, Forest Service 1979b) for the National Forests is representative of the current state of the art. Harden (1980) has shown that there are cases in which specific National Forest analyses can be extrapolated to nearby State land, at least in terms of area-wide economic efficiency.

Several problems remain, however, even for economic efficiency analysis. A gap will always exist between what is theoretically desirable and what is practical to apply, given the limitations of time available for management decisions and the cost of information needed for available models. The models are compromises between what should and what can be done. A similar situation exists for values, value changes, and values-at-risk. Theoretically, these should all be measured and expressed in monetary terms but this may not be practical. For example, much controversy occurs as to how losses should be appraised even for timber, one of the most marketable resources. Selecting the proper method to use for measuring nonmarket values is even more difficult and will always be somewhat subjective and arbitrary. At the far extreme of measurement and monetary expression difficulty are noneconomic resource values, such as endangered species habitat. The noneconomic value must be recognized and considered, however, in determining fire management policy and practice. The potential for rare but large and disastrous conflagrations must also be considered even though conventional economic efficiency analyses are poorly suited to incorporate such events.

In contrast to the well developed state of the art for economic efficiency, the issue of economic equity has received little attention. Serious attention should be devoted to the question of who pays, or should pay, the costs and who obtains the benefits of wildfire management programs. With such information, more complete economic efficiency models, and improved resource value data, it should be possible to provide improved and more specific guidelines for fire management, which will result in economically efficient and equitable programs.

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KEY WORDS: Economic models, economic theory, wildfire economics, net value change, economic efficiency, economic equity

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North Central Forest Experiment Station

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FIREFAMILY: Fire Planning with Historic Weather Data

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FIREFAMILY: FIRE PLANNING WITH HISTORIC WEATHER DATA

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One of the missions of wildland fire management is to integrate fire with other land management activities to achieve desired objectives at the lowest cost. When fire managers know how fires are likely to behave in an area as well as that area's associated weather, topography, and fuel moistures, they can establish limits for public and industrial activities, plan prescriptions for burning, pre-position and dispatch suppression resources, and select appropriate wildfire suppression tactics. This publication will show fire managers how to employ FIREFAMILY, a computer program that uses historic weather data to predict future fire management needs. The publication also identifies the various options available within FIREFAMILY'S major routines.

The three major routines of FIREFAMILY are FIRDAT, SEASON, and FIRINF. In the routine FIRDAT, fire weather station characteristics are combined with daily weather records and the equations of the National Fire-Danger Rating System (NFDRS) to produce **frequency distributions tables** and **graphs** of the NFDRS indexes and components. These **frequency tables** and **graphs** are useful for determining manning levels. For an explanation of the NFDRS, see Deeming *et al.* (1977), Burgan *et al.* (1979), and Helfman *et al.* (1980). SEASON and FIRINF re-read data created by FIRDAT and organize it into probabilities, seasonal graphs, calendars, and other fire management tools.

In the following sections, we discuss each of these three major routines, emphasizing what you will be required to provide as well as how you can analyze the various products. We also provide an Appendix to acquaint you with the Fort Collins Computer Center (FCCC) job-control language required to operate this program. Because FIREFAMILY continually grows to meet users' needs, you might notice slight differences between the output used for illustration and that received from the Fort Collins computer. For updated instructions, contact the Cooperative Fire Protection Staff of the USDA Forest Service at Boise, Idaho (Boise Interagency Fire Center, 3905 Vista Avenue, Boise, Idaho, 83705).

FIRDAT ROUTINE

You will begin the analysis of your data by providing information to FIRDAT on lead cards. This information includes the station's elevation, latitude, fuel model, slope class, herbaceous type, and climate class (see Appendix I). FIRDAT will read this information as well as your historical weather data on file at the National Fire Weather Data Library (NFWDL) (see Furman and Brink 1975).

FIRDAT examines your weather data on a daily basis to determine the best option to use in computing the daily fuel moistures. Then, using the NFDRS equations, FIRDAT calculates the NFDRS components and indexes. These daily values of weather, indexes, and components can be saved for later use; they **must** be saved if you are going to use SEASON and/or FIRINF. You can request a printout of these values called the **daily list.**

An innovative aspect of this routine allows you to define the specific dates for a fire season for a particular protection area. This feature is particularly helpful if you have a split fire season. For example, in the Northeast fires occur frequently in both the spring and the fall, but few fires occur in the summer. You might select April 10, for example, as the beginning of the fire season and November 9 as its end on lead card one (Appendix Ia). Then on lead card two (Appendix Ib), you would exclude the summer period from June 21-September 11 when there are few fires. FIRDAT would then provide a frequency analysis for only the high risk spring and fall periods.

FIRDAT always prints a **summary of station statistics** for each year you select. When the data for your station end, the routine prints **frequency distributions tables** and **graphs** for those NFDRS indexes and components you chose on lead card one.

Header Page

FIREFAMILY always prints a **header page** (fig. 1) showing the information you supplied on your lead cards. Always keep your **header page** attached to the output as a permanent record of the input you used for that run. The **header page** repeats character-by-character the information you supplied. The program then inspects your lead cards for consistency and format. For instance, if the weather information read by the computer is not for your station, or is outside the years that you specified on your lead card, you will receive an error message.

The large block number 240107 on our **header page** (fig. 1) is the weather station number. Bold letters **A** and **B** point out the information supplied on the FIRDAT lead cards. Letter **C** identifies a SEASON lead card and letter **D** identifies two FIRINF lead cards. Note that you can provide up to three separate lead cards for both SEASON and FIRINF. In our example **(D)** we provided two lead cards, which resulted in two separate FIRINF runs.

The routine prints a KEY line under the lead CARD line to identify the entries immediately above it. Find ! = PASSING FILE (above **E**) on lead card one. The KEY character "!" is associated with the **passing file**, an essential FIREFAMILY component that passes FIRDAT data to SEASON and FIRINF. Now find the "!" in the KEY line. Look directly above the "!" and find a "T." The "T" stands for true, indica
that a **passing file** was created in this run. Ar
(false) there would have meant that the **passin**
would not be created and would not be availabl
use with SEASON and FIRINF.

Daily List

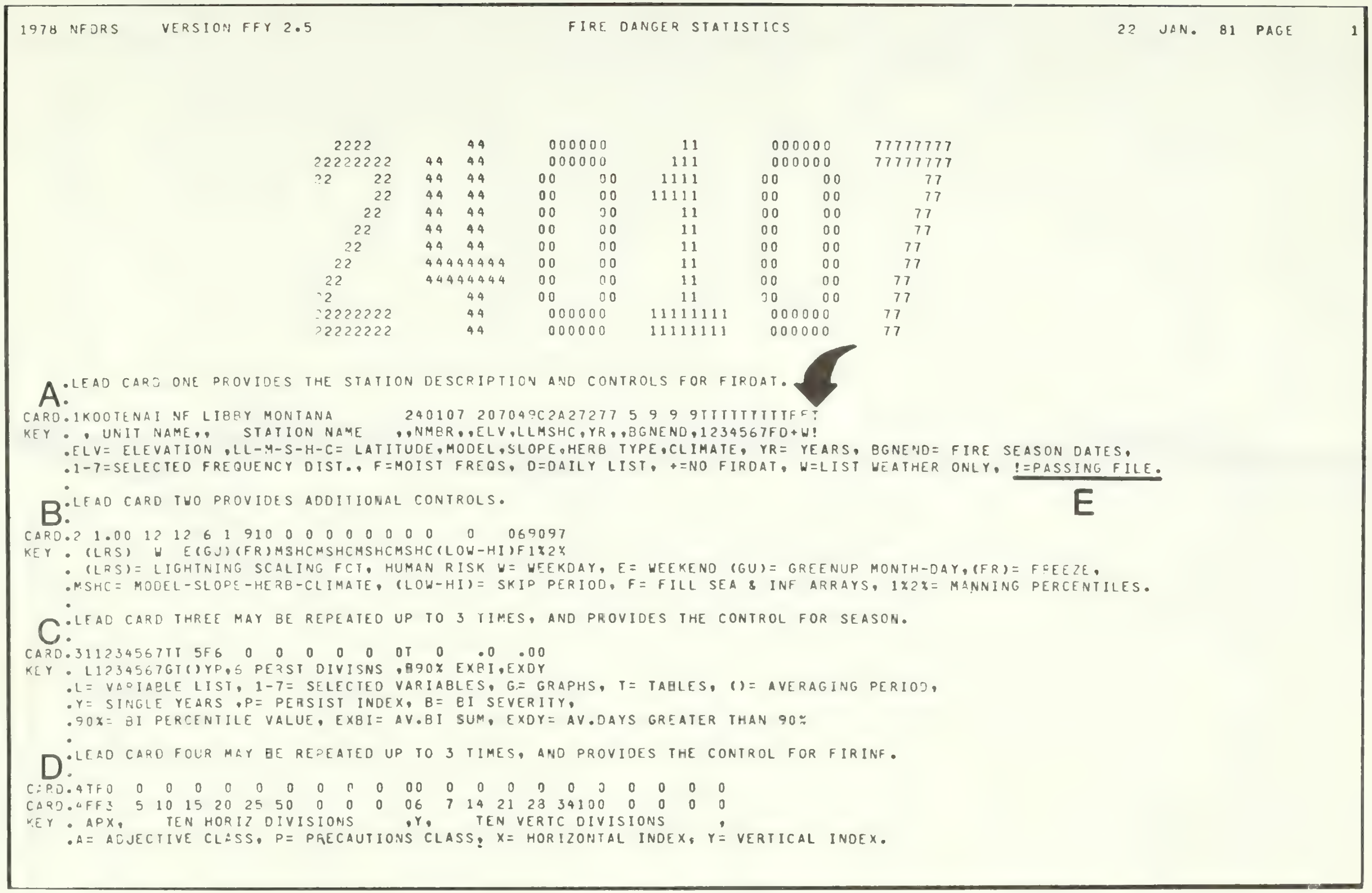
If you choose to print the weather data, the rou
will print the **daily list** (fig. 2). Always examine
daily list closely to ensure that the historical wea
elements on the left hand side correspond to
original weather records.

At the top of each page the title "DAILY L
appears. Included on the left are the FIREFAM
version number "1978 NFDRS VERSION FFY
the administrative ownership "KOOTENAI NF,'
station name and number "LIBBY MONTA
240107," and the user-selected MODEL—"C," SL
CLASS—"2," HERB TYPE—"A," and CLIM
CLASS—"2." Included on the right are the dat
the run, page number, station elevation and latit
and the fire season dates.

Bold **A** indicates abbreviated column headi
From left to right, these abbreviations stand for:
of observations; processing option; state of the weat
dry bulb temperature; relative humidity; wind sp
maximums and minimums of temperature and
ative humidity; amount and duration of preci
tion; lightning activity level; human-caused risk
six fuel moistures: woody, herbaceous, 1-hour,
hour, 100-hour, and 1,000-hour; NFDRS compone
ignition, spread, and energy release; NFDRS
dexes: human-caused fire occurrence, lightning-ca
fire occurrence, burning, and fire load.

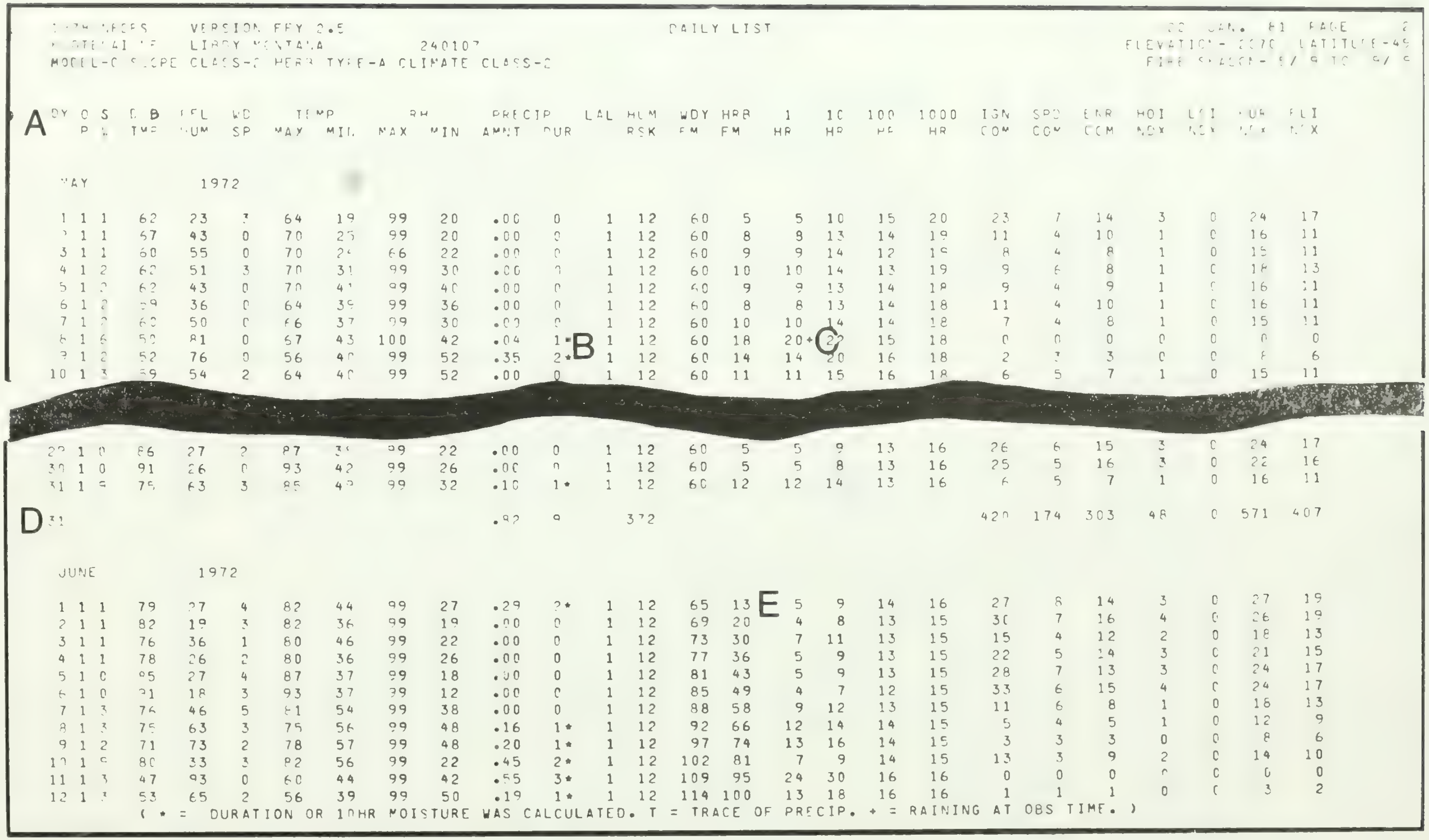
Three special symbols may appear in the print
An asterisk "*" after either the precipitation d
tion or the 10-hour moisture indicates that t
values were computed rather than read from
data **(B)**. A plus sign "+" after the 1-hour mois
shows that it was raining at observation time
A "T" after a zero "0" in precipitation amount
dicates a trace. A key to this information appea
the bottom of each **daily list** page.

At the end of each month, FIRDAT produc
summary report **(D)** of the number of days in



```
1978 NFDRS     VERSION FFY 2.5                         FIRE DANGER STATISTICS                                      22   JAN.   81  PAGE      1



                               2222          44       000000        11        000000     77777777
                             22222222    44  44       000000       111        000000     77777777
                             22     22   44  44     00     00     1111      00     00          77
                                    22   44  44     00     00    11111      00     00          77
                                   22    44  44     00     00       11      00     00         77
                                  22     44  44     00     00       11      00     00         77
                                 22      44  44     00     00       11      00     00        77
                                22       44444444   00     00       11      00     00        77
                               22        44444444   00     00       11      00     00       77
                              22             44     00     00       11      00     00       77
                             22222222        44       000000     11111111     000000        77
                             22222222        44       000000     11111111     000000        77

   .LEAD CARD ONE PROVIDES THE STATION DESCRIPTION AND CONTROLS FOR FIRDAT.
   .
CARD.1KOOTENAI NF LIBBY MONTANA       240107 207049C2A27277 5 9 9 9TTTTTTTTTFFT
KEY . , UNIT NAME,,    STATION NAME    ,,NMBR,,ELV,LLMSHC,YR,,BGNEND,1234567FD+W!
   .ELV= ELEVATION ,LL-M-S-H-C= LATITUDE,MODEL,SLOPE,HERB TYPE,CLIMATE, YR= YEARS, BGNEND= FIRE SEASON DATES,
   .1-7=SELECTED FREQUENCY DIST., F=MOIST FREQS, D=DAILY LIST, +=NO FIRDAT, W=LIST WEATHER ONLY, !=PASSING FILE.
   .
   .LEAD CARD TWO PROVIDES ADDITIONAL CONTROLS.
   .
CARD.2 1.00 12 12 6 1 910 0 0 0 0 0 0 0 0    0    069097
KEY . (LRS)  W  E(GJ)(FR)MSHCMSHCMSHCMSHC(LOW-HI)F1%2%
   . (LRS)= LIGHTNING SCALING FCT, HUMAN RISK W= WEEKDAY, E= WEEKEND (GU)= GREENUP MONTH-DAY,(FR)= FREEZE,
   .MSHC= MODEL-SLOPE-HERB-CLIMATE, (LOW-HI)= SKIP PERIOD, F= FILL SEA & INF ARRAYS, 1%2%= MANNING PERCENTILES.
   .
   .LEAD CARD THREE MAY BE REPEATED UP TO 3 TIMES, AND PROVIDES THE CONTROL FOR SEASON.
   .
CARD.311234567TT 5F6  0  0  0  0  0  0T  0   .0  .00
KEY . L1234567GT()YP,6 PERST DIVISNS ,B90% EXBI,EXDY
   .L= VARIABLE LIST, 1-7= SELECTED VARIABLES, G= GRAPHS, T= TABLES, ()= AVERAGING PERIOD,
   .Y= SINGLE YEARS ,P= PERSIST INDEX, B= BI SEVERITY,
   .90%= BI PERCENTILE VALUE, EXBI= AV.BI SUM, EXDY= AV.DAYS GREATER THAN 90%
   .
   .LEAD CARD FOUR MAY BE REPEATED UP TO 3 TIMES, AND PROVIDES THE CONTROL FOR FIRINF.
   .
CARD.4TF0  0  0  0  0  0  0  0  0  0  00  0  0  0  0  0  0  0  0  0  0
CARD.4FF3  5 10 15 20 25 50  0  0  0  06  7 14 21 28 34100  0  0  0  0
KEY . APX,    TEN HORIZ DIVISIONS     ,Y,    TEN VERTC DIVISIONS       ,
   .A= ADJECTIVE CLASS, P= PRECAUTIONS CLASS, X= HORIZONTAL INDEX, Y= VERTICAL INDEX.
```

Figure 1.—*Header page.*



```
1978 NFDRS     VERSION FFY 2.5                                DAILY LIST                    22  JAN.  81  PAGE    2
[illegible]    LIBBY MONTANA           240107                                      ELEVATION - 2070  LATITUDE-49
MODEL-C SLOPE CLASS-2 HERB TYPE-A CLIMATE CLASS-2                                    FIRE SEASON- 5/ 9 TO  9/ 9

DY O S  D B  FFL  WD    TEMP      RH      PRECIP   LAL HUM  WDY HRB   1   10  100 1000  IGN  SPD  ENR  HOI  LOI  BUR  FLI
   P L  TMP  HUM  SP  MAX  MIN  MAX  MIN  AMNT DUR      RSK  FM  FM   HR  HR  HR   HR   COM  COM  COM  NDX  NDX  NDX  NDX

 MAY        1972

 1 1 1  62   23   3   64   19   99   20   .00   0    1  12   60   5    5  10   15   20   23    7   14    3    0   24   17
 2 1 1  67   43   0   70   25   99   20   .00   0    1  12   60   8    8  13   14   19   11    4   10    1    0   16   11
 3 1 1  60   55   0   70   24   66   22   .00   0    1  12   60   9    9  14   12   19    8    4    8    1    0   15   11
 4 1 2  62   51   3   70   31   99   30   .00   0    1  12   60  10   10  14   13   19    9    6    8    1    0   18   13
 5 1 2  62   43   0   70   41   99   40   .00   0    1  12   60   9    9  13   14   18    9    4    9    1    0   16   11
 6 1 2  59   36   0   64   39   99   36   .00   0    1  12   60   8    8  13   14   18   11    4   10    1    0   16   11
 7 1 2  60   50   0   66   37   99   30   .00   0    1  12   60  10   10  14   14   18    7    4    8    1    0   15   11
 8 1 6  50   81   0   67   43  100   42   .04   1*   1  12   60  18   20+ 22   15   18    0    0    0    0    0    0    0
 9 1 2  52   76   0   56   40   99   52   .35   2*   1  12   60  14   14  20   16   18    2    3    3    0    0    8    6
10 1 3  59   54   2   64   40   99   52   .00   0    1  12   60  11   11  15   16   18    6    5    7    1    0   15   11
29 1 0  86   27   2   87   35   99   22   .00   0    1  12   60   5    5   9   13   16   26    6   15    3    0   24   17
30 1 0  91   26   0   93   42   99   26   .00   0    1  12   60   5    5   8   13   16   25    5   16    3    0   22   16
31 1 9  75   63   3   85   42   99   32   .10   1*   1  12   60  12   12  14   13   16    6    5    7    1    0   16   11

31                                        .92   9       372                                420  174  303   48    0  571  407

 JUNE       1972

 1 1 1  79   27   4   82   44   99   27   .29   2*   1  12   65  13    5   9   14   16   27    8   14    3    0   27   19
 2 1 1  82   19   3   82   36   99   19   .00   0    1  12   69  20    4   8   13   15   30    7   16    4    0   26   19
 3 1 1  76   36   1   80   46   99   22   .00   0    1  12   73  30    7  11   13   15   15    4   12    2    0   18   13
 4 1 1  78   26   2   80   36   99   26   .00   0    1  12   77  36    5   9   13   15   22    5   14    3    0   21   15
 5 1 0  95   27   4   87   37   99   18   .00   0    1  12   81  43    5   9   13   15   28    7   13    3    0   24   17
 6 1 0  91   18   3   93   37   99   12   .00   0    1  12   85  49    4   7   12   15   33    6   15    4    0   24   17
 7 1 3  74   46   5   81   54   99   38   .00   0    1  12   88  58    9  12   13   15   11    6    8    1    0   16   13
 8 1 3  75   63   3   75   56   99   48   .16   1*   1  12   92  66   12  14   14   15    5    4    5    1    0   12    9
 9 1 2  71   73   2   78   57   99   48   .20   1*   1  12   97  74   13  16   14   15    3    3    3    0    0    8    6
10 1 9  80   33   3   82   56   99   22   .45   2*   1  12  102  81    7   9   14   15   13    3    9    2    0   14   10
11 1 3  47   93   0   60   44   99   42   .55   3*   1  12  109  95   24  30   16   16    0    0    0    0    0    0    0
12 1 3  53   65   2   56   39   99   50   .19   1*   1  12  114 100   13  18   16   16    1    1    1    0    0    3    2
        ( * =  DURATION OR 10HR MOISTURE WAS CALCULATED. T = TRACE OF PRECIP. + = RAINING AT OBS TIME. )
```

month, the precipitation amount and duration, and the human-caused risk level. The NFDRS indexes and components are also totaled. This report may be used to chart the monthly progress of your fire season.

The **daily list** also provides a convenient way to learn how changing weather elements affect the fuel moistures and the NFDRS values. It is a complete statement of all that is known from a fire-danger point of view about any particular day, and it can provide information for fire reviews, trespass cases, arson investigations, and other studies when no other measurements were made.

Through the **daily list**, fire managers can also see sudden changes in the character of a particular element such as woody fuel moisture green-up. Note that before green-up on June 1 **(E)** the woody fuel moisture was held constant, and the herbaceous fuel moisture was the same as the 1-hour fuel moisture. At green-up the living fuel moistures begin to increase.

Summary of Station Statistics

The **summary of station statistics** (fig. 3) is printed after each year is processed. The usual heading appears at the top of the page with the title. The year **(A)** for which these data is being summarized is printed below the title. This printout summarizes the lightning fire occurrence indexes for the fire season **(B)** using a lightning scaling factor **(C)** specified on lead card two. The summary also illustrates the pattern of lightning activity level distribution **(D)**. These statistics are required to recalculate the lightning scaling factor for use with the AFFIRMS program. See Appendix D of Deeming *et al.* (1977) for a discussion of this analysis. FIRDAT reports how much data were missing from the official fire season **(E)** and the total number of days processed **(F)**.

The average ignition component is printed to help the fire manager appraise the local adjustment for human-caused fires **(G)** (see Deeming *et al.* 1977, Appendix E). If you have selected the **passing file** (a product of FIRDAT that passes data to SEASON and FIRINF), the total number of records written on it will be noted at the bottom of the final annual summary that you receive **(H)**.

Frequency Distributions Table

FIRDAT sorts all the days in a station's fire season from the lowest to the most extreme fire danger and prints out a **frequency distributions table** (fig. 4). On lead card one you select the indexes, components, and/or fuel moistures for tabulation. You will receive a table for each variable that you select. The table summarizes how often each level of that measure of fire danger occurred.

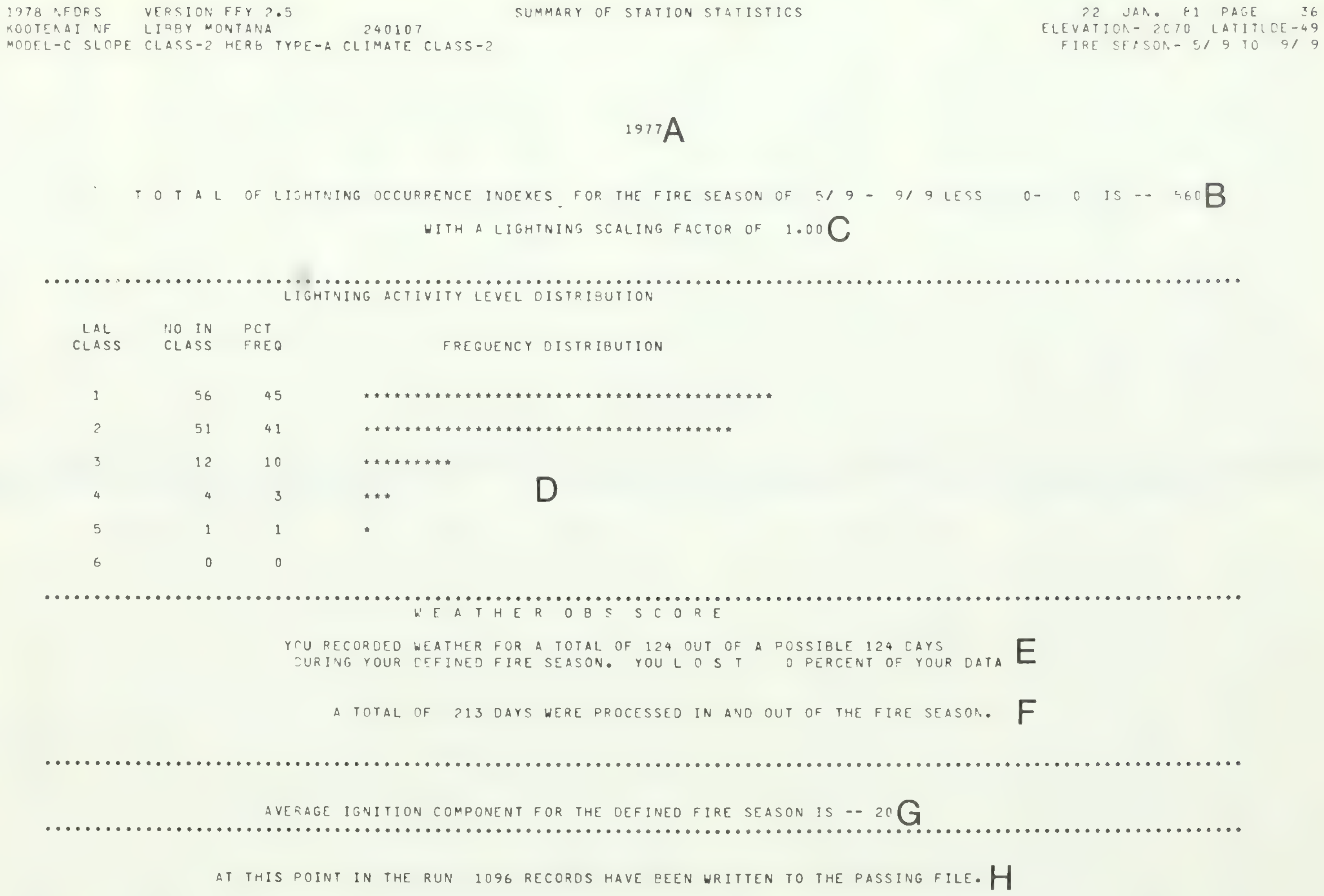
In our example, the burning index **(A)** was the chosen variable. Our table shows the total number of days (731) that fell within the fire season **(B)** and the total number of classes (26) into which the variable is divided **(C)**. To ensure that this table will fit on one page, FIRDAT limits the number of classes to 50. In our example, the BI could range from 0 to 100, so the routine automatically chose a step size of two **(D)**. The sequence is detailed in the upper boundary column.

The first column of this table shows class (or row) numbers. The first row of the table (CLASS NO. 1) gives the number of days with a BI of zero. (When it is raining, zero values are entered in the fire weather observation.) In this example, because the step size is 2, the second row (or CLASS NO. 2) includes days that had burning indexes of 1 and 2 with an upper boundary of 2 **(E)**. The next column **(F)** tells how many days were at those levels of the BI. The relative frequency column **(G)** indicates that the 12 days in row two make up 1.6 percent of the total number of days.

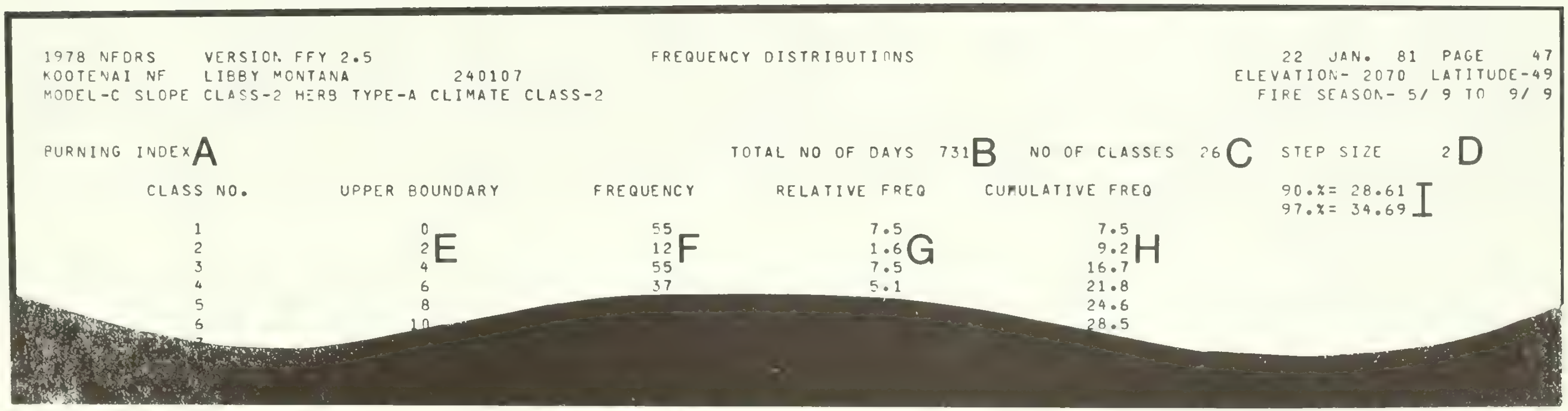
Many agencies use the cumulative frequency **(H)** as the basis for determining their adjective levels or manning classes. Cumulative frequency is the percent of all the days in the fire season that had as small a value as the one indicated in the upper boundary column. In row two, for example, 9.2 percent of the 731 days in the fire season had burning indexes of 2 or less. Often, fire managers determine their manning levels at two specific percentile values. You can specify these two values on lead card two. FIRDAT will use 90th and 97th percentiles **(I)** unless you enter different ones. Our example indicates that the BI has a value of 29 (28.61, rounded up), or less, 90 percent of the time in the fire season. Similarly, the fire manager would expect the BI to be below 35 (34.69, rounded up) at least 97 percent of the time. On the other 3 percent of the days, the burning index will exceed 35.

Frequency Distributions Graph

The points on the **frequency distributions graph** (fig. 5) are the cumulative frequencies listed in the last column of the **frequency distributions table**

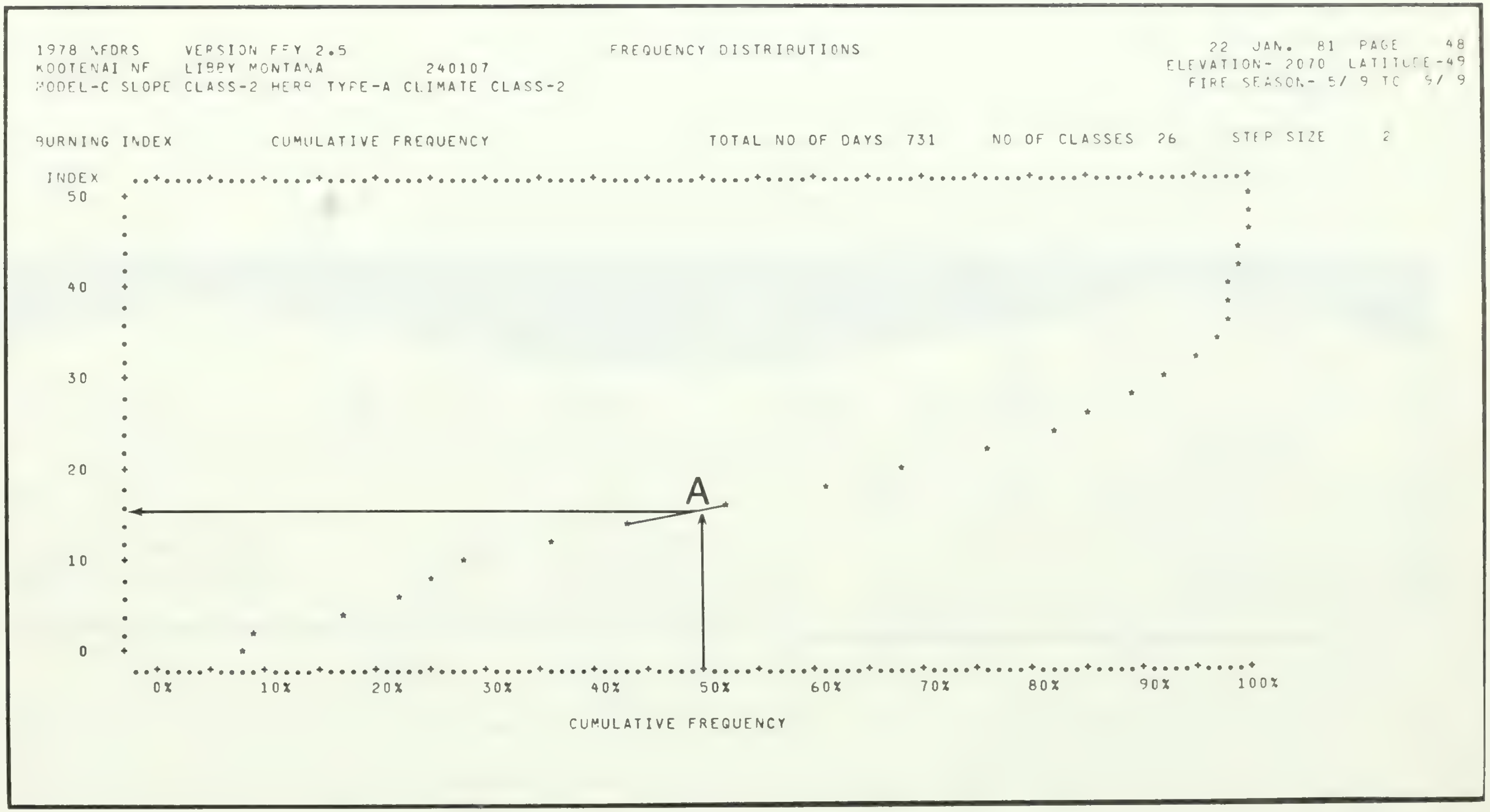


```
1978 NFDRS     VERSION FFY 2.5                         SUMMARY OF STATION STATISTICS                           22  JAN.  81  PAGE    36
KOOTENAI NF    LIBBY MONTANA           240107                                                             ELEVATION- 2070  LATITUDE-49
MODEL-C SLOPE CLASS-2 HERB TYPE-A CLIMATE CLASS-2                                                           FIRE SEASON- 5/ 9 TO  9/ 9


                                                         1977 A


        T O T A L  OF LIGHTNING OCCURRENCE INDEXES  FOR THE FIRE SEASON OF  5/ 9 -  9/ 9 LESS    0-    0  IS --  560 B
                                    WITH A LIGHTNING SCALING FACTOR OF  1.00 C

  ..........................................................................................................
                LIGHTNING ACTIVITY LEVEL DISTRIBUTION

     LAL      NO IN   PCT
    CLASS     CLASS   FREQ                FREQUENCY DISTRIBUTION


      1         56     45       *****************************************

      2         51     41       *************************************

      3         12     10       *********

      4          4      3       ***                   D

      5          1      1       *

      6          0      0

  ..........................................................................................................
                                  W E A T H E R  O B S  S C O R E

                YOU RECORDED WEATHER FOR A TOTAL OF 124 OUT OF A POSSIBLE 124 DAYS
                 DURING YOUR DEFINED FIRE SEASON.  YOU L O S T     0 PERCENT OF YOUR DATA  E

                    A TOTAL OF  213 DAYS WERE PROCESSED IN AND OUT OF THE FIRE SEASON.    F

  ..........................................................................................................

                AVERAGE IGNITION COMPONENT FOR THE DEFINED FIRE SEASON IS -- 20 G
  ..........................................................................................................

            AT THIS POINT IN THE RUN  1096 RECORDS HAVE BEEN WRITTEN TO THE PASSING FILE. H
```



```
1978 NFDRS     VERSION FFY 2.5                   FREQUENCY DISTRIBUTIONS                          22  JAN.  81  PAGE    47
KOOTENAI NF    LIBBY MONTANA         240107                                                  ELEVATION- 2070  LATITUDE-49
MODEL-C SLOPE CLASS-2 HERB TYPE-A CLIMATE CLASS-2                                              FIRE SEASON- 5/ 9 TO  9/ 9

PURNING INDEX                                          TOTAL NO OF DAYS  731   NO OF CLASSES  26    STEP SIZE      2

      CLASS NO.        UPPER BOUNDARY        FREQUENCY        RELATIVE FREQ    CUMULATIVE FREQ      90.%= 28.61
                                                                                                    97.%= 34.69
          1                   0                 55                7.5              7.5
          2                   2                 12                1.6              9.2
          3                   4                 55                7.5             16.7
          4                   6                 37                5.1             21.8
          5                   8                                                   24.6
          6                  10                                                   28.5
```

Figure 4.—*Frequency distributions table.*



```
1978 NFDRS    VERSION FEY 2.5                         FREQUENCY DISTRIBUTIONS                                22  JAN.  81  PAGE    48
KOOTENAI NF   LIBBY MONTANA          240107                                                        ELEVATION- 2070  LATITUDE-49
MODEL-C SLOPE CLASS-2 HERB TYPE-A CLIMATE CLASS-2                                                     FIRE SEASON- 5/ 9 TO  9/ 9

BURNING INDEX         CUMULATIVE FREQUENCY                  TOTAL NO OF DAYS  731     NO OF CLASSES  26     STEP SIZE      2
```

Figure 5.—*Frequency distributions graph.*

(fig. 4). This graph allows you to find the cumulative percentage of days in your fire season that are exceeded by any value of the chosen variable. In our example, the vertical line at the 50th percentile **(A)** intersects the **frequency distributions graph** near the BI of 16. Thus, on half of the days in the fire season the BI will be approximately 16 or less.

Manning Level Table

Frequency distributions are often used to determine agency manning levels. One method for calculating the upper boundaries for six manning levels is shown in table 1.[1] We used our **frequency distributions table** (fig. 4, **I**) to find the upper boundaries for the 90th and 97th percentiles of the BI. Then we divided the 90th percentile value (29) according to the formulas shown to obtain the upper boundaries of the other classes. Remember that the lower boundary of the lowest range is 0, but the upper boundary of the extreme range is limited only by the index or component selected.

Observed Weather Elements

FIREFAMILY allows you to request a printout of **observed weather elements** (fig. 6). (Note: choosing this feature will suppress all other FIREFAMILY features.) The column headings **(A)** are similar to those in the daily list, except that no fire-danger rating values are calculated or printed. This is the only FIREFAMILY listing that shows how the relative humidity was measured **(B)**. In our example, RH indicates that relative humidity was measured directly, instead of being estimated from a wet-bulb or a dew point temperature. This printout is also the only one that shows the wind direction **(C)**. Data fields that were not measured **(D)** are indicated with a "B."

FIRDAT Lead Card One

The information that the fire manager provides on the lead cards is vital to the success of FIREFAMILY routines. Every time FIREFAMILY is run, you must provide lead cards one and two. The options you choose will determine the results obtained as well as the costs of running the program.

Table 1.—*An example of a 6-level manning class table*

Manning class	Description	Burning index	Calculation formulas	Upper boundaries of manning classes
6	Extreme	36 +	Above the 97th percentile	(100 +)
5	Very high	30-35	97th percentile (from table)	35
4	High	23-29	90th percentile (from table)	29
3	High moderate	16-22	90th percentile/1.33 = 21.75	22
2	Low moderate	8-15	90th percentile/2 = 14.5	15
1	Low	0-7	90th percentile/4 = 7.25	7

NOTE: The lower boundary in each manning class is one more than the upper boundary of the next lowest class. Set the upper boundary of the extreme class high enough to accommodate the most extreme values of your variable

You begin coding lead card one (Appendix Ia), by placing a 1 in the first card column. Then continue by coding with the administrative owner's name, station name and number, elevation in feet, and latitude. For example, KOOTENAI NF; LIBBY MONTANA; 240107; 2,070 feet; and 49° were coded in card columns 2-46.

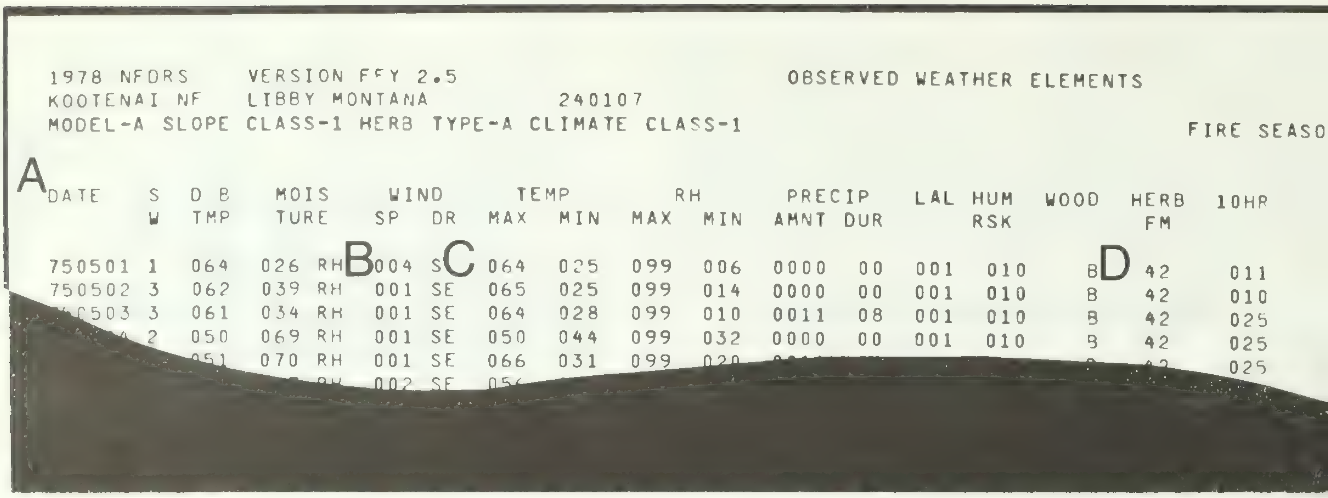
Next, you must specify a model-slope-herb-climate combination. Ordinarily this will be the same combination you use for your daily weather observations. You should use all of the weather data available to you at the National Fire Weather Data Library. If you code 00 for the beginning of the range of years and 99 for the ending year in item 8, you will obtain output for all of your station's historic weather data.

FIRDAT allows you to specify the beginning and ending months and days of your fire season in item 9. Your fire season may begin in the fall and end in the spring or vice-versa. Note: You may skip over periods of low fire danger by specifying them on lead card two, item 6.

From now on, your selections on lead card one become crucial. For example, if you choose the variable or variables your agency uses for planning, your FIREFAMILY run will be more helpful. If you choose all the variables, you might generate excess paper. You may choose up to eight variables in item 10: ignition component, spread component, energy release, human-caused fire occurrence, lightning fire occurrence, burning index, fire load index, and/or fuel moistures. Code a "T" (true) in the appropriate column for each variable you want to see. Place an "F" (false) in the columns of the variables you don't want. If you code a "T" for fuel moistures, you will get all four: 1-hour, 10-hour, 100-hour, and 1,000-hour.

---

[1] *See Appendix E of the AFFIRMS manual for an example of a 10-manning class table.*



```
1978 NFDRS     VERSION FFY 2.5                              OBSERVED WEATHER ELEMENTS
KOOTENAI NF    LIBBY MONTANA           240107
MODEL-A SLOPE CLASS-1 HERB TYPE-A CLIMATE CLASS-1                                              FIRE SEASO

DATE      S   D B    MOIS       WIND      TEMP          RH         PRECIP     LAL  HUM   WOOD   HERB   10HR
          W   TMP    TURE     SP   DR   MAX   MIN   MAX   MIN   AMNT  DUR         RSK           FM

750501 1   064    026 RH   004  S    064   025   099   006   0000   00   001   010     B   42     011
750502 3   062    039 RH   001  SE   065   025   099   014   0000   00   001   010     B   42     010
  0503 3   061    034 RH   001  SE   064   028   099   010   0011   08   001   010     B   42     025
       2   050    069 RH   001  SE   050   044   099   032   0000   00   001   010     B   42     025
           051    070 RH   001  SE   066   031   099   020                                        025
                     RH   002  SE   056
```

Figure 6.—*Observed weather elements.*

Next, you should decide if you wish to see the **daily list** of weather, components, and indexes. Place a "T" in column 71 to see the **daily list.** If you have already seen the **daily list**, placing an "F" in column 71 will save you money. Coding an "A" will be expensive, because it will cause the routine to print **daily lists** for all of the model-slope-herb-climate combinations that you select on lead card two.

The most important dollar-saving feature of FIREFAMILY is its ability to skip over FIRDAT when you have saved your **passing file** from a previous FIRDAT run. Code "T" in column 72 to skip FIRDAT and go directly to SEASON and/or FIRINF. Placing an "F" in column 72 will cause normal FIRDAT operation.

Placing a "T" in column 73 activates the weather-only feature (**observed weather elements**—fig. 6) of FIREFAMILY. Always place an "F" in column 73 unless you want only the raw weather data.

Placing a "T" in column 74 will cause the program to create a **passing file** (the file that passes information to SEASON and FIRINF). Because it is expensive to create the information on the **passing file**, you should save this file for later use with FIRINF and/or SEASON.

FIRDAT Lead Card Two

Lead card two (Appendix Ib) gives you other FIRDAT options. You can provide information about risk assessments, dates for green-up and curing, up to four combinations of model-slope-herb-climate, and you may specify a split fire season. If you are going to run SEASON and FIRINF together with FIRDAT, you may choose one index or component to determine your manning levels. You may also redefine the u per boundaries of your manning percentiles on lea card two.

If you don't know your lightning risk scaling fa tor (LRS), use the value 01.00 in columns 2-6 of lea card two. If you run FIRDAT again, you should co sult Deeming *et al.* (1977, Appendix D) to revie guidelines for computing the lightning risk scalir factor. (See fig. 3, **B**, to find the total of lightnir occurrence indexes in our example.)

You must provide estimates on lead card two f weekday and weekend human risk. The weekd (W) and weekend (E) values may range from 0 100 and should be recorded in columns 7-9 and 1 12.

Next, select the month and day when herbaceo plants usually start to green-up at your station. Co the month in card columns 13-14 and the day in 1 16. (Key abbreviation for green-up on lead card t in fig. 1 is GU.) Continue by specifying the earlie month and day on which you expect fall curing begin. Herbaceous plants will not necessarily die this day; instead FIRDAT begins to look for weath conditions that indicate freezing. If, for instance, hard frost occurs with a minimum temperature 25° or less, the NFDRS will "cure" the herbaceo fuels immediately. If no hard frost occurs, FIRD automatically records curing and dormancy after t fifth day with a minimum temperature of less th 33°. If minimum temperatures were not observed f your station, the date you specified in columns 1 20 will be used as the curing date. If your area nev experiences freezing, enter 1232 in columns 17-2

Because of diverse fuel types and topography, you might want to process your data with more than one combination of model, slope, herbaceous class, and climate. If so, indicate as many as four additional combinations in card columns 21-36. For example, if you have two different forest types near your weather station, you could process the data for upland hardwood stands (NFDRS Model E) and, with the same set of lead cards, process the conifer types (NFDRS Model H). If, on lead card two, you change your climate class or herbaceous code, you may have to use a new lead card one to redefine the green-up and curing dates.

Many parts of the country have a two-part fire season. The Southeast, for example, has a fall season of October and November and a spring season of February to April. With that pattern, running cumulative frequencies for dates of October to April will include the 2 months of low fire occurrence (December-January), thereby biasing the results. To avoid this bias, skip the low risk period by coding its beginning month in columns 37-38, the beginning day in columns 39-40, the ending month in columns 41-42, and the ending day in columns 43-44. If you do not have a split fire season, leave these columns blank.

The first time you use FIREFAMILY, you should run FIRDAT by itself, saving the **passing file**. You can then analyze the FIRDAT cumulative frequency tables to find the index values necessary to calculate your manning classes. If you want to include SEASON and/or FIRINF in the first run, FIRDAT provides an option that calculates a set of ranges for one index. Choose the number of the variable (1-7) from the list in item 7 and code it in card column 45 (see Appendix Ib). This code will cause FIRDAT to calculate the ranges that will become the rows and/or columns for your SEASON and FIRINF tables. **However, we strongly recommend that you do not attempt to run SEASON or FIRINF in the first run with FIRDAT**.

The USDA Forest Service uses the 90th and 97th percentiles to delineate the high and very high manning levels. If your agency uses other values, you should enter them in columns 46-47 and 48-49 on lead card two.

SEASON ROUTINE

The severity of fire weather changes during the year. The SEASON routine summarizes these variations and reveals seasonal patterns over many years to help fire managers plan. SEASON will tabulate and/or graph the values of any of the fuel moistures, indexes, or components the fire manager wishes to analyze.

SEASON has three major sections: **seasonal tables** and **graphs**, monthly **persistence probability tables**, and the cumulative **BI seasonal severity list** and **summary table.** The **seasonal tables** show the average, highest, and lowest values of the chosen variable for each day of the year. **Seasonal graphs** map the general character of the fire season shown in the **seasonal tables**. The **persistence probability tables** report the chance that tomorrow's variable will be the same as today's. The **BI seasonal severity summary table** ranks the fire seasons of each year according to their difficulty, based on the 90th percentile of the burning index. Remember that BI severity measures only the effect of weather, not fire activity.

Seasonal Table

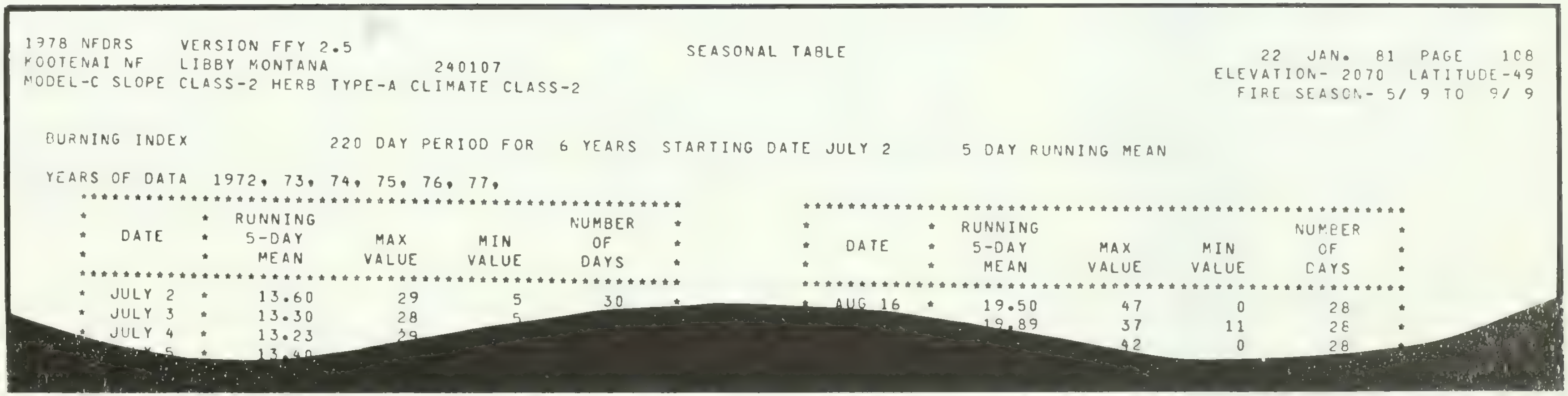
The **seasonal table** shows—for each variable you select—the mean, maximum, and minimum values for the averaging period as well as the number of weather observations recorded over the period of years indicated at the top of the table (fig. 7). All the observed data are included in the **seasonal table**, not just the data from the fire season. To save money and paper, choose only the variable(s) most important for planning.

In figure 7, we chose the BI. We also selected an averaging period of 5 days. This running mean is an average calculated from an odd number of consecutive days, centered on the observation date. The longer the period chosen for the running mean, the smaller the day-to-day changes in the average will be. This "smoothing" of the daily averages will make a graph of this information easier to interpret. Smoothing periods of 3 to 7 days are usual.

Graphing Options

SEASON provides the option for graphing the tabulated information in figure 7. If you ask for such a graph (Appendix Ic, card column 10 = T), you will get one page of printout for every 2 months shown in the table. You will also receive a graph legend that explains symbols used, years included, and the scale the computer selected to lay out the graph.

SEASON can also graph the data 1 day at a time, year after year. This feature might give you insight into a particularly bad year or show how drought affects out-of-season wildfires. **Be careful, however, because this feature can generate massive volumes of paper**. To save paper and money, select



```
1978 NFDRS     VERSION FFY 2.5                          SEASONAL TABLE                                   22  JAN.  81  PAGE   108
KOOTENAI NF    LIBBY MONTANA          240107                                                   ELEVATION- 2070  LATITUDE-49
MODEL-C SLOPE CLASS-2 HERB TYPE-A CLIMATE CLASS-2                                               FIRE SEASON- 5/ 9 TO  9/ 9

  BURNING INDEX              220 DAY PERIOD FOR  6 YEARS  STARTING DATE JULY 2      5 DAY RUNNING MEAN

  YEARS OF DATA  1972, 73, 74, 75, 76, 77,
    ****************************************************           ****************************************************
    *          *  RUNNING                          NUMBER   *           *          *  RUNNING                          NUMBER   *
    *   DATE   *   5-DAY      MAX       MIN          OF     *           *   DATE   *   5-DAY      MAX       MIN          OF     *
    *          *    MEAN     VALUE     VALUE        DAYS    *           *          *    MEAN     VALUE     VALUE        CAYS    *
    ****************************************************           ****************************************************
    *  JULY 2  *   13.60      29         5          30      *           *  AUG 16  *   19.50      47         0          28      *
    *  JULY 3  *   13.30      28         5
    *  JULY 4  *   13.23      29                                                       19.89      37        11          28      *
    *     X 5  *   13.4                                                                           42         0          28      *
```

Figure 7.—Seasonal table.

the variable or variables of greatest concern (columns 3-9, Appendix Ic), use the combination of model-slope-herb-climate on lead card one only, and turn off the SEASON tables (column 11 = F). To activate this **single year graph** feature, code column 14, lead card 3, with a "T."

Fire Manager's Graph

You can easily hand draw a graph of your own data. Figure 8 is a graph of the seasonal variations of the BI. We used graph paper that already included a year-by-day legend along the bottom. To find the range of the variable which we were plotting, we consulted our **frequency distributions table** (fig. 4). Because the BI ranges from 0 to 50, we used that range for our vertical scale. The **frequency distributions table** also gives the upper boundaries of the 90th and 97th percentiles. We used these values as well as the information contained in table 1 to draw five horizontal manning class lines. Bold **A** (fig. 8) shows that we drew the line for the upper boundary of our 90th percentile at a BI of 29 (28.61, rounded up).

Next, we transferred the daily mean values from the **seasonal table** (fig. 7) to the graph and connected them with a smooth line. (We used a running mean of 5 days to smooth our curve.) This curve shows the seasonal variation in the burning index. Finally, we drew vertical lines at the beginning **(B)** and end **(C)** of our fire season.

You could also plot your daily maximum and minimum values from the **seasonal table**. Once you have graphed your historical weather curve, you can use this graph to compare your current daily values with the averages. Lay a clear plastic sheet over your historical graph and plot current observed values on it.

If you asked for the computer printed graphs of the **seasonal tables**, you could draw the manning levels and the seasonal curve on them, but it would be difficult to overlay a plastic sheet on such a large graph.

Persistence Probability Table

Persistence measures how likely something is to remain the same. The fraction of the time that the weather will be the same tomorrow as it is today is tabulated in the SEASON's **persistence probability table** (fig. 9). The higher the persistence, the less likely the weather will change. SEASON produces monthly **persistence probability tables** for the chosen variable.

Information at the top of the table indicates the total number of years, the month for which data are being tabulated, and the specific years included. One page of output will be produced for each month of data. In our example, the burning index is divided into six manning classes (table 1). These six classes make up both the row and column headings in each of the three parts of figure 9. Today's BI's are found in the rows **(A)** and tomorrow's BI's are found in the columns **(B)**. The ranges illustrated in the **persistence probability table** were computed by FIRDAT. However, you can select them by coding on lead card three (see Appendix Ic, item 9).

The **persistence probability table** reports the total number of pairs of days that were found **(C)**. (A pair occurs whenever there are weather observations on 2 consecutive days.) Out of a possible 186 pairs (31 days x 6 years), 175 pairs were found. The greatest number of pairs occurred when the BI was in the 16-22 class 1 day and continued in the same class through the next day 38 times **(D)**.

Figure 9 is divided into three parts. The top third tells how many times each pair of BI 's (today's and tomorrow's) falls within each of the manning class ranges (both rows and columns). In our example, **E** shows that the BI was in the extreme range 2 days in a row (both today and tomorrow) four times in the 6 years under study.

The middle third tells what percentage of the time a BI today was followed by each of the BI ranges tomorrow. The bottom row of the middle section **(F)** shows that if our BI is 36-50 today, then 45 percent (45.45) of the time tomorrow's BI will be in the 23-29 range. The chance that today will be followed by the next range (30-35) is 18 percent. Finally, the chance that the BI tomorrow will be in the same range as it is today is 36 percent. The fire manager would use this section of the table to predict the range of tomorrow's burning index by today's BI. The fire manager would want to pay particular attention to very high or extreme conditions. As the previous example showed, if the BI is in the extreme range today, the chances are about one in three (36 percent) that tomorrow's BI will also be in the extreme range. These historic data is used primarily for planning how long to keep firefighters ready to handle the worst fires.

The bottom third of the figure indicates the percentage of the time that any particular combination of today's and tomorrow's values occurs. For example, the occurrence of extreme days following one another **(G)** is only 2.29 percent of the time in August. This means that the fire organization should

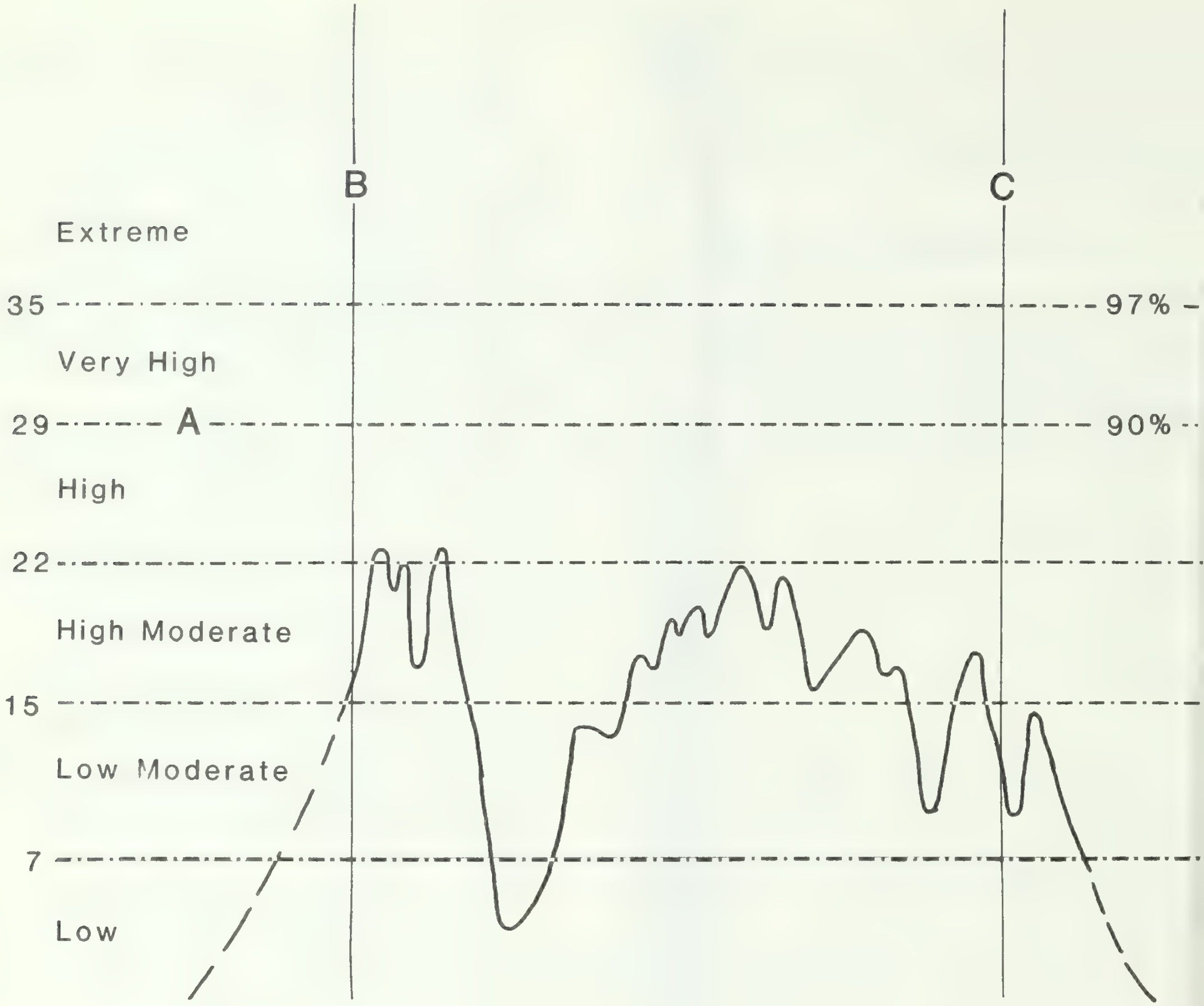


Figure 8.—*Fire manager's hand-drawn seasonal graph of the BI.*

plan to have 2 of their worst days back-to-back about once each August (2.29 percent of 31 days in August = 0.71 days, or about once every August).

Note: If you want to see your persistence probability, **don't** turn on the **single year graph** feature in SEASON.

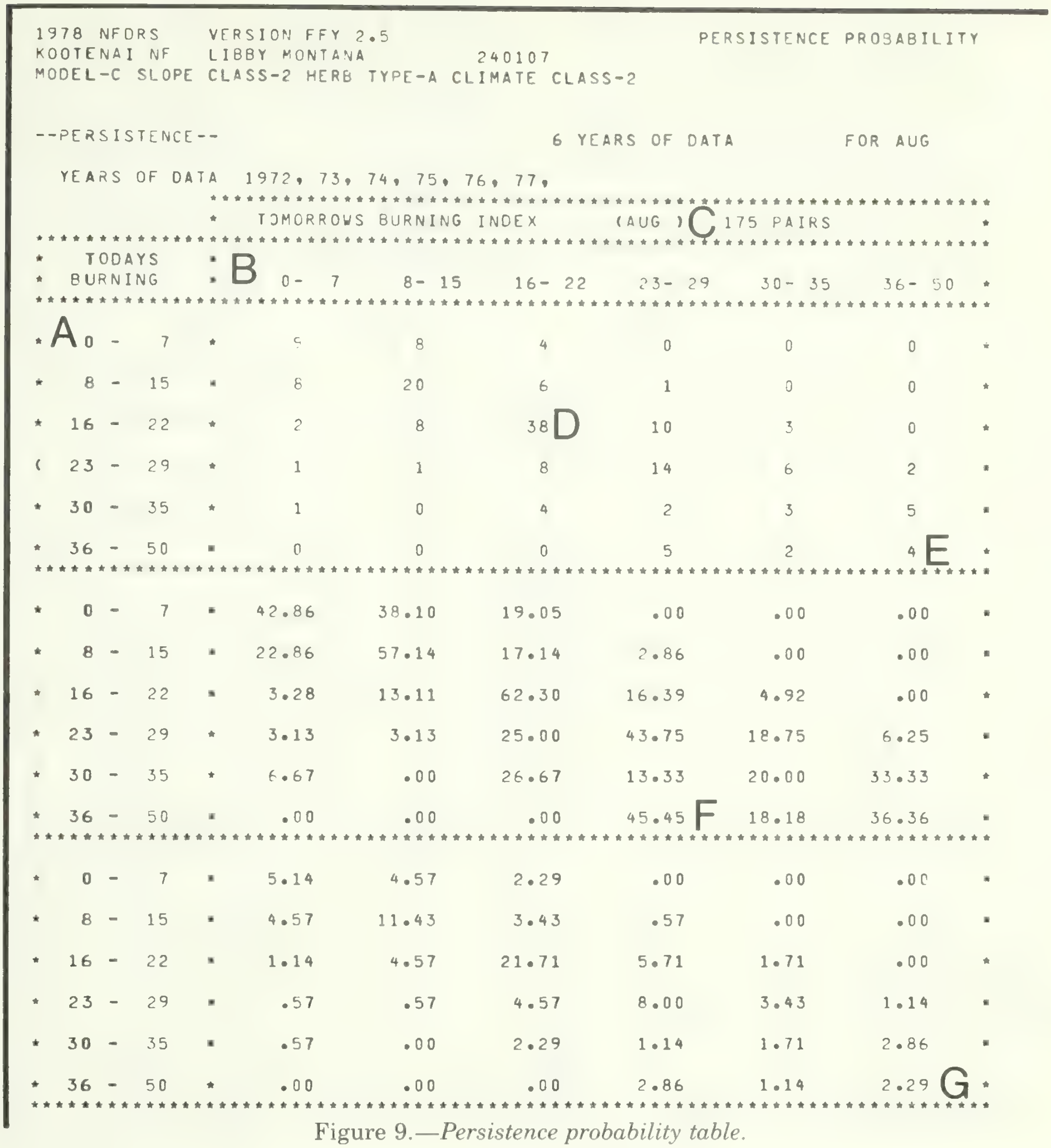
BI Seasonal Severity

The seasonal severity routine uses the burning index to rank how severe the fire weather was each year. Seasonal severity both lists those days that have a BI exceeding the 90th percentile and summarizes the data by months and year.

BI Seasonal Severity List

The **BI seasonal severity list** (fig. 10) ranks eac year at a fire weather station in terms of the burnin index. The ranking takes into account both how ofte and by how much each day's BI exceeded the 90t percentile BI level. The column headings **(A)** identif the dates that exceeded the 90th percentile BI, th BI value on these dates, the cumulative departure and finally, the number of days in that year that th BI exceeded the 90th percentile BI. The progra shows the upper boundary of the 90th percentile B (90% = 29) **(B)**.

We see that the first day in 1972 to exceed th 90th percentile value was May 19. The differenc



```
1978 NFDRS     VERSION FFY 2.5                             PERSISTENCE PROBABILITY
KOOTENAI NF    LIBBY MONTANA           240107
MODEL-C SLOPE CLASS-2 HERB TYPE-A CLIMATE CLASS-2

--PERSISTENCE--                                 6 YEARS OF DATA         FOR AUG

  YEARS OF DATA  1972, 73, 74, 75, 76, 77,
                 ********************************************************************
                 *   TOMORROWS BURNING INDEX       (AUG )C 175 PAIRS                *
*****************************************************************************************
*   TODAYS      *B
*  BURNING      *   0-  7      8- 15     16- 22     23- 29     30- 35     36- 50    *
*****************************************************************************************
*A 0 -    7     *     9          8          4          0          0          0      *
*   8 -   15    *     8         20          6          1          0          0      *
*  16 -   22    *     2          8         38D        10          3          0      *
(  23 -   29    *     1          1          8         14          6          2      *
*  30 -   35    *     1          0          4          2          3          5      *
*  36 -   50    *     0          0          0          5          2          4E     *
*****************************************************************************************
*   0 -    7    *   42.86      38.10      19.05        .00        .00        .00    *
*   8 -   15    *   22.86      57.14      17.14       2.86        .00        .00    *
*  16 -   22    *    3.28      13.11      62.30      16.39       4.92        .00    *
*  23 -   29    *    3.13       3.13      25.00      43.75      18.75       6.25    *
*  30 -   35    *    6.67        .00      26.67      13.33      20.00      33.33    *
*  36 -   50    *     .00        .00        .00      45.45 F    18.18      36.36    *
*****************************************************************************************
*   0 -    7    *    5.14       4.57       2.29        .00        .00        .00    *
*   8 -   15    *    4.57      11.43       3.43        .57        .00        .00    *
*  16 -   22    *    1.14       4.57      21.71       5.71       1.71        .00    *
*  23 -   29    *     .57        .57       4.57       8.00       3.43       1.14    *
*  30 -   35    *     .57        .00       2.29       1.14       1.71       2.86    *
*  36 -   50    *     .00        .00        .00       2.86       1.14       2.29 G  *
*****************************************************************************************
```

Figure 9.—*Persistence probability table.*

(31–29 = 2) was entered in the cumulative departure column. The cumulative departure totals the daily departures (Daily departures = BI $_{today}$–BI $_{90percentile}$). The August 11 daily departure (31–29 = 2) was added to the previous two cumulative departure points to equal four cumulative departure points and so on.

Our example also shows the beginning of the 1973 fire season **(C)** where we note 7 days in a row exceeding the 90th percentile BI. Such periods would force a fire suppression group to respond day after day at its maximum strength.

BI Seasonal Severity Summary Table

The data in the **BI seasonal severity list** are summarized in the **BI seasonal severity summary table** (fig. 11). The months **(A)** are listed horizontally above the summarized information. The cumulative departures and the number of days above the 90th percentile value for all the months are tabulated **(B)**. Both the total departures and the day counts **(C)** indicate that 1973 was about 14 times more severe than average. The annual ratings for 1973 **(D)** show

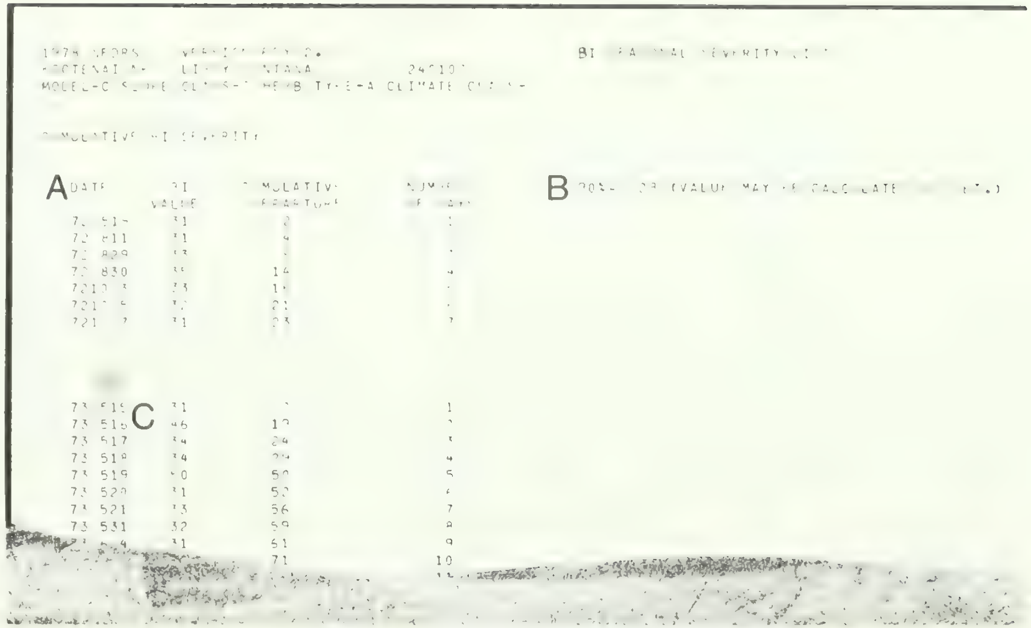
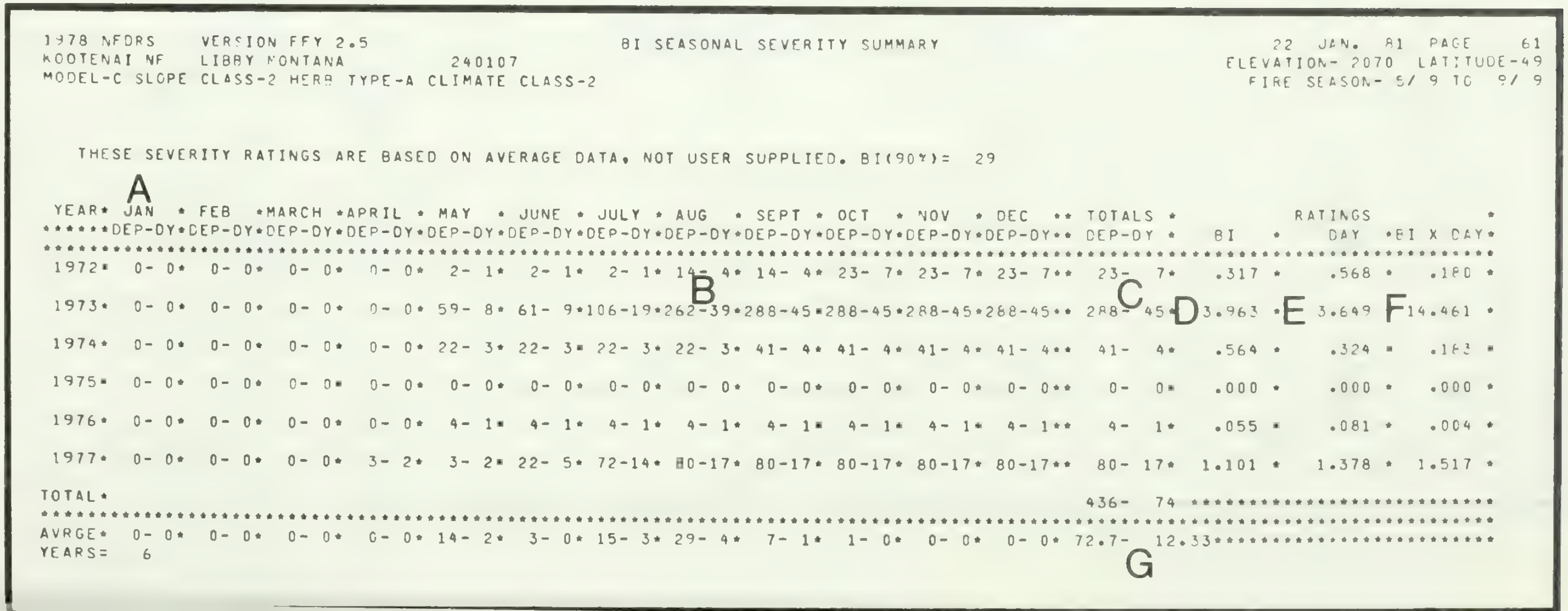


Figure 10.—*BI seasonal severity list.*



```
1978 NFDRS     VERSION FFY 2.5                               BI SEASONAL SEVERITY SUMMARY                                    22  JAN.  81  PAGE    61
KOOTENAI NF    LIBBY MONTANA            240107                                                                         ELEVATION- 2070  LATITUDE-49
MODEL-C SLOPE CLASS-2 HERB TYPE-A CLIMATE CLASS-2                                                                         FIRE SEASON- 5/ 9 TO  9/ 9


  THESE SEVERITY RATINGS ARE BASED ON AVERAGE DATA, NOT USER SUPPLIED. BI(90%)=  29

 YEAR* JAN   * FEB   *MARCH *APRIL  * MAY   * JUNE  * JULY  * AUG   * SEPT  * OCT   * NOV   * DEC   ** TOTALS *             RATINGS            *
******DEP-DY*DEP-DY*DEP-DY*DEP-DY*DEP-DY*DEP-DY*DEP-DY*DEP-DY*DEP-DY*DEP-DY*DEP-DY*DEP-DY** DEP-DY *    BI    *    DAY   *BI X DAY*
*************************************************************************************************************************************
 1972*  0- 0*  0- 0*  0- 0*  0- 0*  2- 1*  2- 1*  2- 1* 14- 4* 14- 4* 23- 7* 23- 7* 23- 7**  23-  7*   .317 *    .568 *   .180 *

 1973*  0- 0*  0- 0*  0- 0*  0- 0* 59- 8* 61- 9*106-19*262-39*288-45*288-45*288-45*288-45** 288- 45*  3.963 *   3.649 * 14.461 *

 1974*  0- 0*  0- 0*  0- 0*  0- 0* 22- 3* 22- 3* 22- 3* 22- 3* 41- 4* 41- 4* 41- 4* 41- 4**  41-  4*   .564 *    .324 *   .163 *

 1975*  0- 0*  0- 0*  0- 0*  0- 0*  0- 0*  0- 0*  0- 0*  0- 0*  0- 0*  0- 0*  0- 0*  0- 0**   0-  0*   .000 *    .000 *   .000 *

 1976*  0- 0*  0- 0*  0- 0*  0- 0*  4- 1*  4- 1*  4- 1*  4- 1*  4- 1*  4- 1*  4- 1*  4- 1**   4-  1*   .055 *    .081 *   .004 *

 1977*  0- 0*  0- 0*  0- 0*  3- 2*  3- 2* 22- 5* 72-14* 80-17* 80-17* 80-17* 80-17* 80-17**  80- 17*  1.101 *   1.378 *  1.517 *

TOTAL*
                                                                                                436-  74 ***************************
*************************************************************************************************************************************
AVRGE*  0- 0*  0- 0*  0- 0*  0- 0* 14- 2*  3- 0* 15- 3* 29- 4*  7- 1*  1- 0*  0- 0*  0- 0* 72.7-  12.33***************************
YEARS=   6
```

that the total departures were 3.963 times greater than the average. Similarly the ratings day **(E)** shows that there were 3.649 more days above the 90th percentile than normally occur. The product of the BI and day columns **(F)** for 1973 is 14.461. The average annual departure and number of days are reported at **(G)**. Our example shows that in these 6 years, the average BI departure was 72.7 and the average number of days above the 90th percentile was 12.33. Because the station has a 123-day fire season, we expected about 10 percent of the days to exceed the 90th percentile level.

Remember that this method evaluates the weather of each year, not wildfire activity.

SEASON Lead Card Three

Appendix Ic describes the coding necessary for the SEASON routine. Coding a 3 in card column 1 (item 1) identifies a SEASON lead card. SEASON can plot the NFDRS components and indexes (item 3, list 1), the weather elements (item 3, list 2), or the living and dead fuel moistures (item 3, list 3). You choose the list you want by coding the number 1, 2, or 3 in card column 2. Then from that list select the variables that you want tabulated or graphed. You **must** select one list and at least one variable or SEASON will not function. Leave the card column blank for every variable you don't want tabulated or graphed.

You may select **seasonal graphs, tables**, or both by coding a "T" or "F" in columns 10 and 11 (items 4 and 5). The averaging period for graphs and tables (columns 12-13) must be an odd number between 01 and 31 (item 6). If you choose 1 day, a jagged graph will result. Increasing the averaging period will "smooth" the graph (see fig. 8 for an example). Use 3, 5, or 7 days as your running mean for a "smoothed" graph.

If you want a graph of individual years, code "T" in column 14 (item 7). Because this feature has limited value, you will usually code "F." Note well: The single **year graph feature** automatically turns off **BI seasonal severity list** and **summary table** and **persistence probability tables**. It may also create excessive paper and expense (see Appendix II, item 7).

If you don't wish to receive a **persistence probability table**, enter a 0 in column 15, item 8. To get a **persistence probability table**, however, you must choose one of the indexes or components from item 3 that you coded in columns 3-9. Code the number of the variable in column 15. (In our example in fig. 9, we had coded list number 1 in card column 2 and coded 6 in column 8, so we could again code 6—the burning index—in card column 15.)

You will usually run FIRDAT first, analyze the data, and then run SEASON. (SEASON will get all its weather data from the **passing file**.) As part of this analysis, you will find the 90th and 97th percentile values of your variable on your **frequency distributions table** (fig. 4, I). Item 9 tells you to code your upper boundary levels in columns 16-33 on lead card three. In our example (table 1), we would code 007 in columns 16-18, 015 in columns 19-21, and so on.

You can force FIRDAT to compute the upper boundaries of the variable chosen in item 8 by running FIRDAT and SEASON at the same time and placing the number of the variable from the list in item 3 into column 45 on lead card two. The computer will then automatically calculate the upper and lower boundaries and you need not fill in columns 16-33 in item 9 on lead card three.

You may have the **BI seasonal severity list** and **summary table** printed by placing a "T" in column 34 (item 10). If this SEASON run immediately follows a FIRDAT run, SEASON will remember the 90th percentile value of the BI, so leave item 11 blank. However, if you run SEASON independently with the **passing file**, then you must specify the 90th percentile BI in columns 35-37.

The **BI seasonal severity summary table** (fig. 11) can be produced in two ways. If this is a run with FIRDAT, you should leave columns 38-47 blank. The routine will calculate the average departure points and number of days and print them (fig. 11, G). Later, you may wish to compare the BI seasonal severity with different average values for the departures and number of days. You can instruct the routine to use these values by placing them in card columns 38-47. In our example, the columns on lead card three were left blank and the computer determined the average values.

FIRINF ROUTINE

Although SEASON deals with only one NFDRS variable at a time, FIRINF can provide information on combinations of two variables. Many agencies combine two variables to determine their adjective or manning classes. For example, fire managers often combine the IC (a measure of fire occurrence) with the BI (a measure of fire intensity) to determine these classes. They could then use these FIRINF tables for planning detection flights, wildfire prevention activities, industrial closures, and specific action guides. Both SEASON and FIRINF get their data from the **passing file** produced by FIRDAT. The FIRINF routine uses only the first 3,600 days of historical weather data, so you may wish to decide which 10 years are most important to you and code them on a new lead card one (see Appendix Ia, item 8).

Adjective Class Matrix

The **adjective class matrix** (fig. 12) is one of the most frequently used fire management tools. It combines the IC with the agency's manning class index or component to help provide the public with fire-danger levels.

Figure 12 demonstrates how the BI was used to provide the manning levels. The values FIREFAMILY computed for you or that you entered on lead card four (Appendix Id) are displayed at **A** in figure 12. The first pair of "x values" **(B)** shown (0-20) defines the boundaries of the first column. Each subsequent pair defines another column. The **adjective class matrix** always includes the same five ranges of the ignition component. The first "y value" pair (0-7) defines the first row of the BI. The other pairs define the remaining rows.

In figure 12, the row with a BI of 23-25 shows two "M's" (moderate), two "H's" (high), and a "V" (very high) in the columns from left to right. Other symbols found in the matrix are "L" (low) and "E" (extreme). A summary of the number of days in the data base and the number of days actually used is shown at the bottom of the printout.

This table provides the fire manager with a quick overview of how the IC and BI together affect the adjective class levels. For clarity we have outlined the area of the table containing the very high and extreme days **(C)**.

Instead of the **adjective class matrix**, you can obtain the **precautions class matrix**, a similar table often used to determine forest closures. The **precautions class matrix** uses a different range of column headings for the IC and allows the user to choose the variable (often the energy release component or the BI) to determine the manning levels.

FIRINF also provides you with an opportunity to form your own matrix to give you more information than that offered in either the **adjective** or **precautions class matrices**. You may combine any two of the seven variables listed on lead card four to produce the user-defined matrix. You may have to use a second or third lead card four for this purpose. Place "F's" in columns 2 and 3. Code the first variable number in column 4 and the second in column 35 and specify up to 10 upper boundaries of each index or component in the provided card columns (see Appendix Id).

Adjective Class Calendar

The **adjective class calendar** (fig. 13) indicates the adjective levels assigned by the **adjective class matrix** to each day for which you have historical weather data. **Precautions class** or **user-defined matrices** also produce a similar calendar.

FIRINF prints out the date (year—72, month—08, day—09) **(A)**. A dot (.) is printed above the first digit of the year. (Notice that the dates are printed below one another in groups of seven, indenting one column each time.) The adjective class letter (M—moderate) for the first date is printed in the row labeled M. (A row is provided for each class—L, M, H, V, E.) You can easily see the changes in adjective levels on a daily basis.

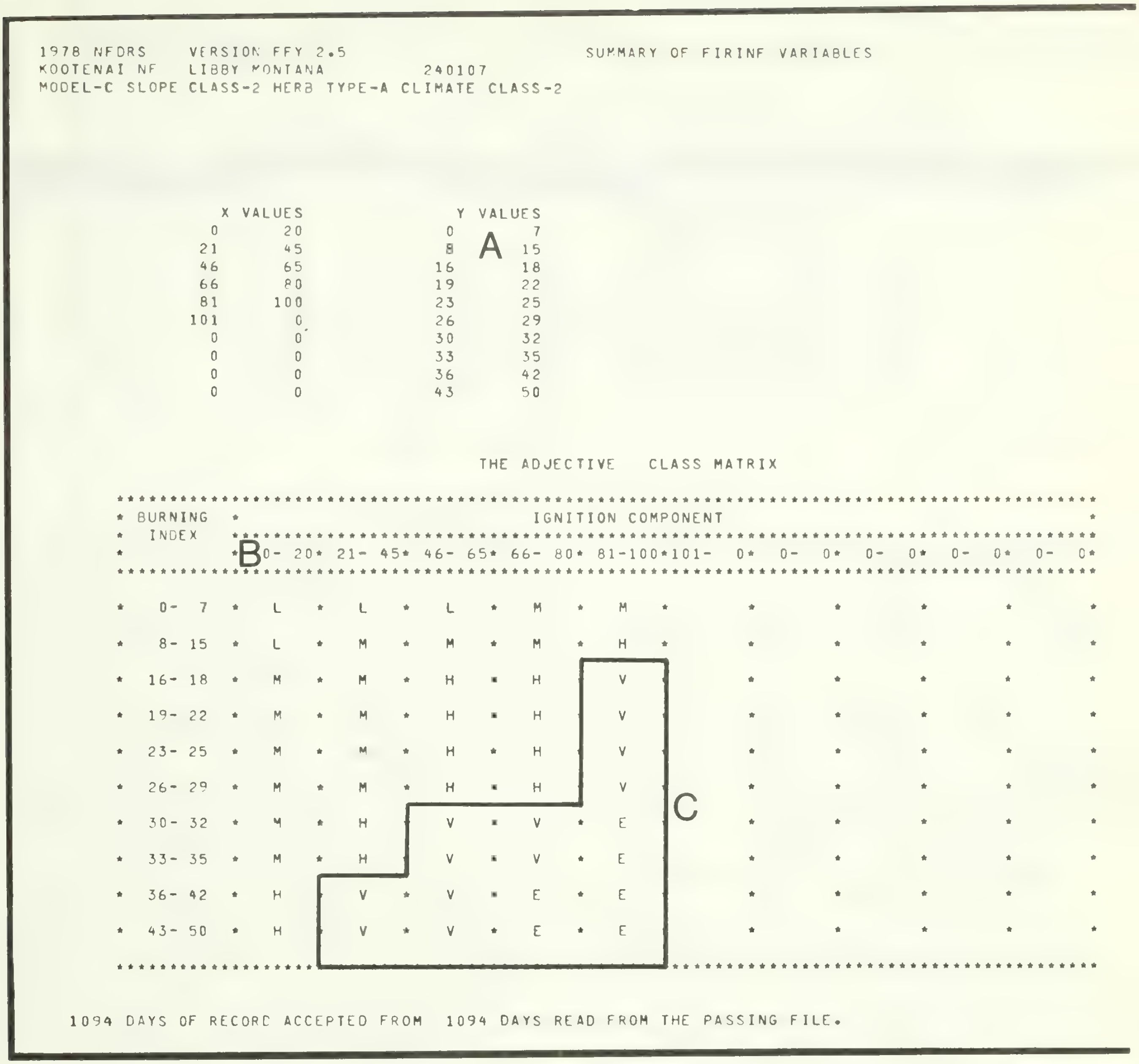
Find August 30, 1972 in the calendar **(B)**. Using a straight edge, draw a line up from the 7 (the first digit of the year) beyond its dot through the letter H **(C)**. Use this method to find the adjective rating for any day in your data base. In general, you will look at your calendar for repeated very high (V) or extreme (E) days. The **adjective class calendar** graphically illustrates persistence of adjective levels. In the **precautions class** and **user-defined matrices**, the letters A, B, C, D, E, and F are used to show class categories. "A" is the lowest level of fire danger.

Probability Analysis

Once you have asked for the **adjective class matrix**, you will get an **adjective class calendar** as well as monthly and annual **probability analysis tables**. These **probability analysis tables** will provide you with some of the detailed information necessary to plan your fire management activities. The tables will show how often you can expect values of your adjective class to occur. In figure 14, the table rows indicate the ranges of numerical values for the BI and the columns indicate the ranges of the ignition component.

The **probability analysis table** is divided into three parts. The top third **(A)** tells how often combinations of the BI and the IC occurred. Our example shows that in the six Augusts for which we have data, there were 17 days when the BI was 19-22 and the IC was in the range of 0-20. On 21 other days, when the BI was 19-22 the IC was in the range of 21-45.

The middle of the table **(B)** tells the percent of the time that the ignition component is in each column, given that the BI is in a particular row. For example, in the BI row labeled 19-22 we see that 44.74 percent



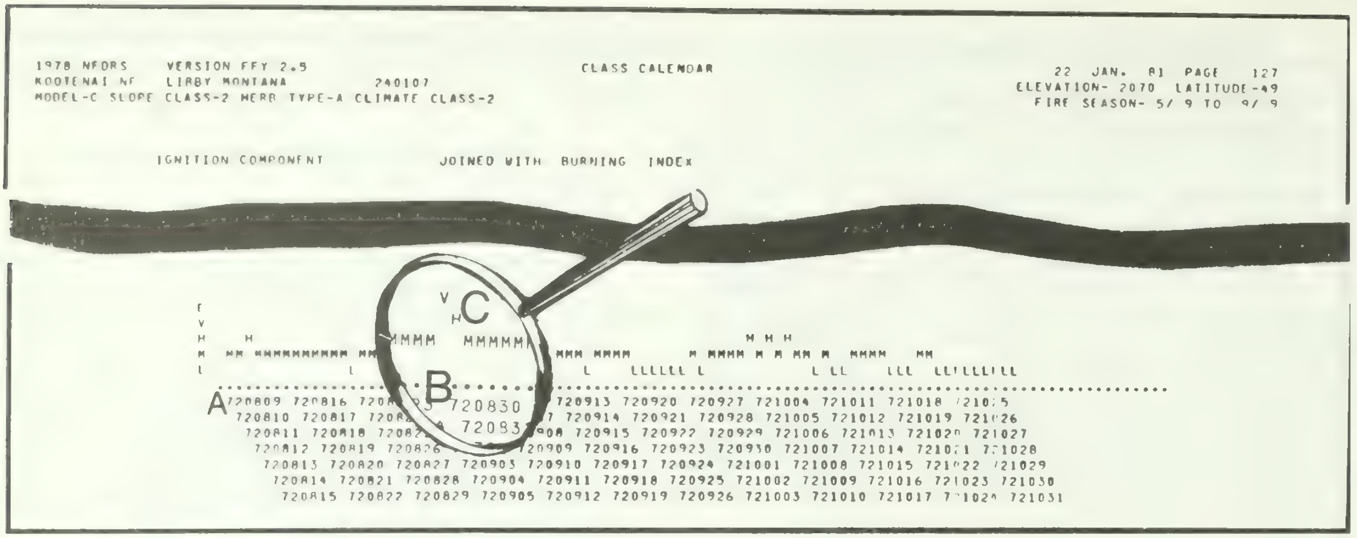
```
1978 NFDRS    VERSION FFY 2.5                              SUMMARY OF FIRINF VARIABLES
KOOTENAI NF   LIBBY MONTANA          240107
MODEL-C SLOPE CLASS-2 HERB TYPE-A CLIMATE CLASS-2



                 X VALUES                Y VALUES
               0      20               0        7
              21      45               8       15
              46      65              16       18
              66      80              19       22
              81     100              23       25
             101       0              26       29
               0       0              30       32
               0       0              33       35
               0       0              36       42
               0       0              43       50


                                       THE ADJECTIVE   CLASS MATRIX

       *******************************************************************************************
       * BURNING  *                              IGNITION COMPONENT                              *
       *  INDEX   ********************************************************************************
       *          * 0- 20* 21- 45* 46- 65* 66- 80* 81-100*101-   0*  0-   0*  0-   0*  0-   0*  0-   0*
       *******************************************************************************************

       *   0-  7  *   L   *   L   *   L   *   M   *   M   *       *       *       *       *       *

       *   8- 15  *   L   *   M   *   M   *   M   *   H   *       *       *       *       *       *

       *  16- 18  *   M   *   M   *   H   *   H       V           *       *       *       *       *

       *  19- 22  *   M   *   M   *   H   *   H       V           *       *       *       *       *

       *  23- 25  *   M   *   M   *   H   *   H       V           *       *       *       *       *

       *  26- 29  *   M   *   M   *   H   *   H       V           *       *       *       *       *

       *  30- 32  *   M   *   H       V   *   V   *   E           *       *       *       *       *

       *  33- 35  *   M   *   H       V   *   V   *   E           *       *       *       *       *

       *  36- 42  *   H       V   *   V   *   E   *   E           *       *       *       *       *

       *  43- 50  *   H       V   *   V   *   E   *   E           *       *       *       *       *

       ******************                                  ****************************************

   1094 DAYS OF RECORD ACCEPTED FROM  1094 DAYS READ FROM THE PASSING FILE.
```

Figure 12.—*Adjective class matrix.*

of the time the ignition component was in the range 0-20 and 55.26 percent of the time the ignition component was in the 21-45 range.

The lower third of the table (**C**) tells the percentage of all the days on which each combination of the BI and IC occurred. Thus in our example, on 9.29 percent of all the August days, the BI was in the range of 19-22 and the ignition component had a value between 0-20. Similarly, on 11.48 percent of the days, the BI was between 19 and 22, and the ignition component ranged from 21-45.

Probability analysis tables are helpful to fire managers using historical weather data for planning and budgeting. On figure 12 we outlined the area of the table containing the very high and extreme days. We have used the same rows and columns to outline the identical portion of figure 14 (**D**). Adding all of the percentages within the outlined area, we find that a total of 7.65 percent of the 186 August days were in the very high or extreme range in the past (31 August days x 0.0765 = 2.37—or more than 2 days per August). Therefore, the fire manager would



```
1978 NFDRS    VERSION FFY 2.5                         CLASS CALENDAR                           22  JAN. 81  PAGE   127
KOOTENAI NF   LIBBY MONTANA          240107                                               ELEVATION- 2070  LATITUDE-49
MODEL-C SLOPE CLASS-2 HERB TYPE-A CLIMATE CLASS-2                                           FIRE SEASON- 5/ 9 TO  9/ 9

         IGNITION COMPONENT             JOINED WITH  BURNING  INDEX
```

Figure 13.—*Adjective class calendar.*

budget for an average of 3 very high and/or extreme days in August each year.

In addition to the monthly **probability analysis tables**, you will receive a yearly **probability analysis table** showing the same kind of information, on an annual basis.

If you ask for a **precautions class** or **user-defined matrix**, you will receive **probability analysis tables** for them also. You can analyze them in the same way that you analyzed the **probability analysis table** for adjective classes.

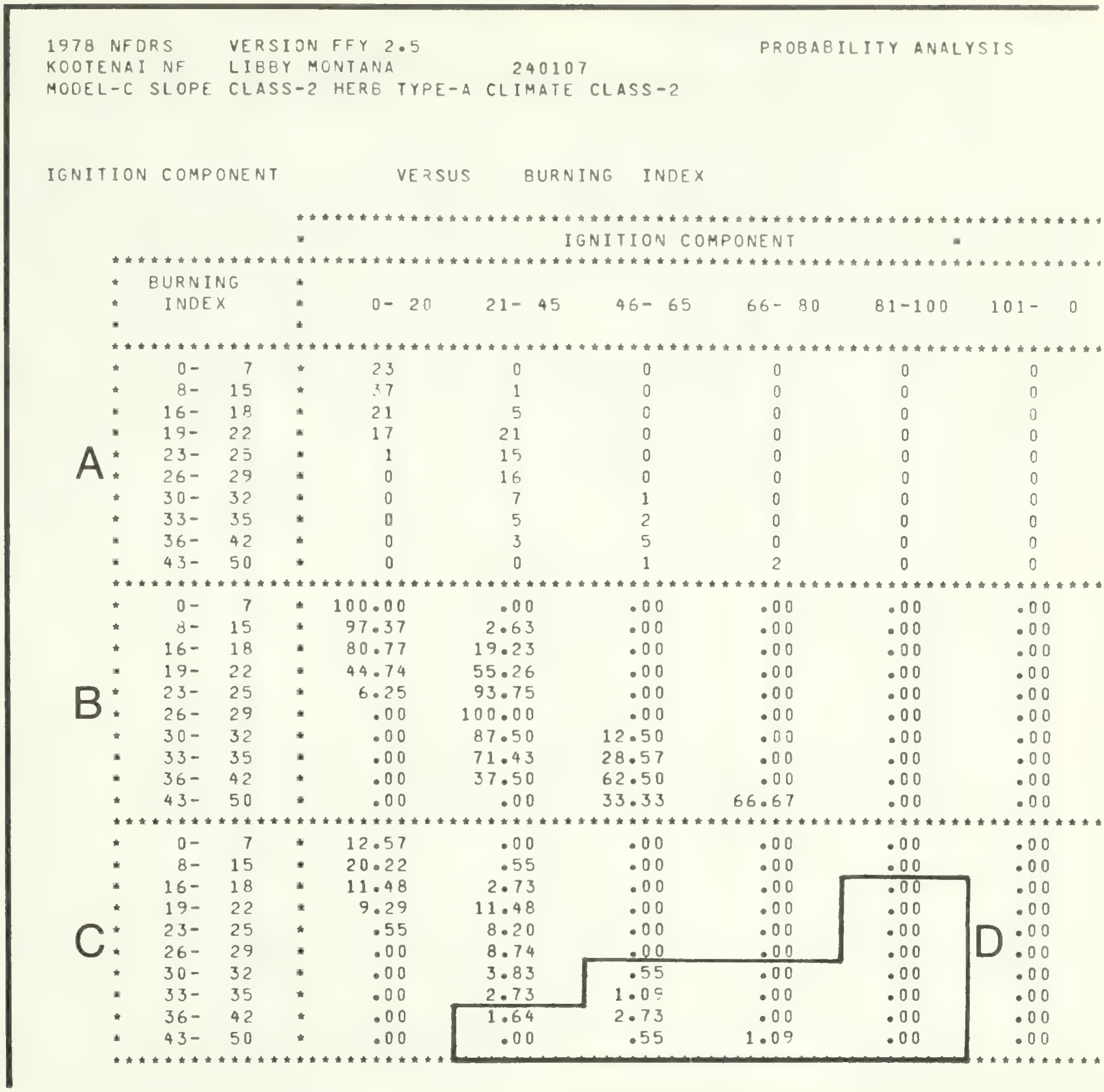
FIRINF Lead Card Four

Two examples of the FIRINF lead card are shown at the bottom of the FIREFAMILY header page (fig. 1, **D**). A "4" punched in card column 1 (Appendix Id, item 1) identifies each FIRINF card. Item 2, Appendix Id, allows the user to select or reject the **adjective class matrix** by coding a "T" (true) or an "F" (false) in card column 2. If you run FIRDAT and FIRINF at the same time and you code a "6" in card column 45 of lead card two, FIRDAT will then compute the upper boundaries of your BI. Because the computer will then automatically provide the ranges of the BI, you need not fill in the rest of lead card four. When requesting the **adjective class matrix**, you must code an "F" in column 3 of lead card four. You can leave card column 4 blank because the IC is always used in the **adjective class matrix**. Both columns 2 and 3 may be coded false.

Usually you will be running FIRINF with a previously created **passing file**. The program will compute the upper boundaries of the IC for you, so leave columns 4-34 blank. But you must code the number of the variable you want combined with the IC into card column 35. Use our table 1 or Appendix E of the AFFIRMS manual to find a method to determine up to 10 upper boundaries of your chosen variable. Enter these boundaries in card columns 36-65.

A similar table to the **adjective class matrix**—the **precautions class matrix**—can be selected by coding an "F" in card column 2 and a "T" in card column 3. Just as for the **adjective class matrix**, if you are running FIRINF with FIRDAT and code number 3 (ERC) in card column 45 of lead card two, FIRDAT will provide the row ranges, so you can leave the rest of lead card four blank. If you have run FIRDAT previously, however, follow the coding routine suggested for the **adjective class matrix**, but use the ERC, the BI, or another variable for the rows.

Instead of selecting either the **adjective** or **precautions class matrices**, you can construct any other table by combining two variables from the list in Appendix Id, item 4. You might wish to construct your own table because your agency does not use the same method for determining manning levels that has been provided by FIRINF, or you may wish to choose indexes or components other than those provided by FIRINF. Code as follows: put the code number of your chosen column variable in card column 4 and the row variable in column 35. Constructing tables this way requires you to enter up to 10 of the upper boundaries for the ranges of the chosen variables. These numbers will appear in the columns and rows on the table you are constructing. Enter upper boundaries for the first variable in card col-



```
1978 NFDRS     VERSION FFY 2.5                          PROBABILITY ANALYSIS
KOOTENAI NF    LIBBY MONTANA          240107
MODEL-C SLOPE  CLASS-2 HERB TYPE-A CLIMATE CLASS-2


IGNITION COMPONENT          VERSUS     BURNING   INDEX

                   *************************************************************
                   *                    IGNITION COMPONENT                 *
*******************************************************************************
  *  BURNING       *
  *   INDEX        *     0- 20     21- 45     46- 65     66- 80     81-100    101-   0
  *                *
*******************************************************************************
  *    0-     7    *       23          0          0          0          0          0
  *    8-    15    *       37          1          0          0          0          0
  *   16-    18    *       21          5          0          0          0          0
  *   19-    22    *       17         21          0          0          0          0
A *   23-    25    *        1         15          0          0          0          0
  *   26-    29    *        0         16          0          0          0          0
  *   30-    32    *        0          7          1          0          0          0
  *   33-    35    *        0          5          2          0          0          0
  *   36-    42    *        0          3          5          0          0          0
  *   43-    50    *        0          0          1          2          0          0
*******************************************************************************
  *    0-     7    *   100.00        .00        .00        .00        .00        .00
  *    8-    15    *    97.37       2.63        .00        .00        .00        .00
  *   16-    18    *    80.77      19.23        .00        .00        .00        .00
  *   19-    22    *    44.74      55.26        .00        .00        .00        .00
B *   23-    25    *     6.25      93.75        .00        .00        .00        .00
  *   26-    29    *      .00     100.00        .00        .00        .00        .00
  *   30-    32    *      .00      87.50      12.50        .00        .00        .00
  *   33-    35    *      .00      71.43      28.57        .00        .00        .00
  *   36-    42    *      .00      37.50      62.50        .00        .00        .00
  *   43-    50    *      .00        .00      33.33      66.67        .00        .00
*******************************************************************************
  *    0-     7    *    12.57        .00        .00        .00        .00        .00
  *    8-    15    *    20.22        .55        .00        .00        .00        .00
  *   16-    18    *    11.48       2.73        .00        .00        .00        .00
  *   19-    22    *     9.29      11.48        .00        .00        .00        .00
C *   23-    25    *      .55       8.20        .00        .00        .00    D   .00
  *   26-    29    *      .00       8.74        .00        .00        .00        .00
  *   30-    32    *      .00       3.83        .55        .00        .00        .00
  *   33-    35    *      .00       2.73       1.09        .00        .00        .00
  *   36-    42    *      .00       1.64       2.73        .00        .00        .00
  *   43-    50    *      .00        .00        .55       1.09        .00        .00
*******************************************************************************
```

Figure 14.—*Probability analysis table.*

umns 5-34, leaving any unused columns blank. Choose up to 10 upper boundaries for the second variable and code these numbers in columns 36-65 (item 7).

CONCLUSION

We have shown how your historical weather data can be combined with the NFDRS to produce a variety of useful planning tools. The **frequency distributions tables** indicate the highest fire-danger levels of each index or component. The SEASON printouts show when to expect periods of sustained high fire danger. Indexes and components are combined in the **adjective** and **precautions class matrices** to provide both the public and private sectors with estimates of potential fire danger.

Now that you have seen what FIREFAMILY can do for you, your next step is to determine what your needs are and submit the appropriate lead cards to your computer specialist. (You can photocopy the lead cards in Appendix I to make coding simpler.) The specialist will then combine your lead cards with the Fort Collins job-control cards shown in Appendix III.

ACKNOWLEDGMENTS

FIREFAMILY began as a collection of separate programs written by several people. The authors gratefully acknowledge R. William Furman and David Rainey, Rocky Mountain Station, Fort Collins, Colorado, for their early contributions to FIREFAMILY. We also thank Roger L. Bradshaw, Boise Interagency Fire Center, for his patience and help in the most recent refining of the program.

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APPENDIX I.—LEAD CARD FORMATS

Two kinds of computer instructions are required to operate FIREFAMILY—program lead cards and job control cards.

Program lead cards are discussed thoroughly in this publication. Below we summarize general information about the program lead cards and suggest general rules for submitting the cards to the computer. Appendix II illustrates the number of pages likely to be produced. Appendix III shows the job-control cards needed to execute FIREFAMILY at Fort Collins and the format of the **passing file**. We have included this information in the Appendices for easy reference by your computer specialist.

There are four types of program lead cards: lead cards one and two control FIRDAT, three controls SEASON, and four controls FIRINF. The identification number, always coded in column 1 of each card, determines how the program interprets the contents of that card. The cards must be properly formatted and submitted to the computer in the correct order. General rules are:

1. The lead cards must be entered from low card number to high for the same weather station.

2. More than one station may be in the same run. (Include a card one for each station.)

3. Order the card "ones" from lowest station number to highest.

4. Lead cards three and four do not have to be present in a run.

5. The first card in an entire group must be a card one.

6. The second card in an entire group must be a card two.

7. Once a card two, three, or four is entered, its instructions will remain in effect until altered by another card of the same type.

8. Cards three and four can exist in multiples of three cards each for the same station.

A.—FIRDAT Control—Lead Card One

ITEM	DESCRIPTION AND CARD COLUMN(S)		
1	Card number		(1) ____
2	Administrative owner's name		(2-13) ____
3	Station name		(14-33) ____
4	Station number		(34-39) ____
5	Station elevation in feet (right justify)		(40-44) ____
6	Station latitude, nearest degree		(45-46) ____
7	NFDRS model-slope-herb-climate class combination. (Lead card two allows you to specify four additional combinations.)		
	Model:	A through U but not M	(47) ____
	Slope:	1 through 5	(48) ____
	Herbaceous:	A or P only, annual or perennial	(49) ____
	Climate class:	1 through 4	(50) ____
8	Range of years:	First year	(51-52) ____
		Last year	(53-54) ____
	(Enter 0099 to get all available data)		
9	Fire season:	Beginning month	(55-56) ____
		Beginning day	(57-58) ____
		Ending month	(59-60) ____
		Ending day	(61-62) ____
	(Enter 0101 and 1231 to include entire year. Lead card two allows you to skip a period of few fires.)		
10	Select the indexes, components, and/or fuel moistures for which **frequency distributions tables** and **graphs** are desired. Code a "T" for those you want, an "F" for those you don't want.		
	Variable		
	Ignition component		(63) ____
	Spread component		(64) ____
	Energy release component		(65) ____
	Human-caused fire occurrence index		(66) ____
	Lightning-caused fire occurrence index		(67) ____
	Burning index		(68) ____
	Fire load index		(69) ____
	Fuel moistures (You will get all four dead FM's: the 1-hr, 10-hr, 100-hr, and 1,000-hr.)		(70) ____
11	"T" produces a **daily list** of the weather, indexes, and components. The program resets this item to "F" after the first model-slope-herb-climate combination has been processed. If you plan to choose more than one combination on lead card two (item 5), and you want to see the **daily list** for each combination, code "A". Coding an "F" will suppress the printing of all **daily lists**.		(71) ____
12	"T" indicates that you already have a FIRDAT-created **passing file**. The routine will bypass FIRDAT and go directly to SEASON and/or FIRINF.		(72) ____
13	"T" causes FIRDAT to list only the observed weather elements. No indexes or components will be printed.		(73) ____
14	"T" causes FIRDAT to create a **passing file** for use with SEASON and/or FIRINF.		(74) ____

B.—FIRDAT Control—Lead Card Two

ITEM DESCRIPTION AND CARD COLUMN(S)

1 Card number (1) 2

2 Lightning risk scaling (LRS) factor. (See Deeming *et al.* 1977, Appendix D). For the first run, enter 01.00, and include the decimal point. On later runs you should adjust your LRS as indicated in INT-39. (2-6) ________

3 Human-caused risk scaling factors. Columns 7-9 contain the average weekday risk. (7-9) ________

Columns 10-12 contain the average weekend risk. (10-12) ________

4a The month and day when green-up normally begins. (13-16) ________

4b The month and day of the first killing frost. (17-20) ________

5 Up to four more model-slope-herb-climate combinations may be entered here (see Appendix Ia, item 7).
(21-24) ________
(25-28) ________
(29-32) ________
(33-36) ________

6 If your station has a split fire season, you may enter the low risk period here.
Beginning month and day (37-40) ________
Ending month and day (41-44) ________

7 You may select one variable from the following list and use its code number to have SEASON and FIRINF construct a variety of tables.
Leave blank if you are not using SEASON and/or FIRINF on this run.

Code	Variable
1	IC
2	SC
3	ERC
4	HCOI
5	LOI
6	BI
7	FLI

(45) ____

8 Your agency's planning methods may vary from those used by the USDA Forest Service. This program will print (and use) the 90th and 97th percentile levels of the index or component chosen in card column 45 if you leave these columns blank. If you code 8095, however, the program will use the 80th and 95th percentile levels. (46-49) ________

C.—SEASON Control—Lead Card Three

ITEM DESCRIPTION AND CARD COLUMN(S)

1 Card number (1) ____

2 SEASON will graph and/or tabulate variables from one of the following lists: 1 = NFDRS, 2 = weather elements, 3 = fuel moistures. Choose one list and code it in card column 2. (2) ____

3 From the list chosen in item 2, select any or all of the variables:

Code	List 1 **NFDRS**	List 2 **Weather Elements**	List 3 **Fuel Moistures**	
1	IC	Temp	1-hour	(3) ____
2	SC	RH	10-hour	(4) ____
3	ERC	Wind	100-hour	(5) ____
4	HCOI	Prec. dur.	1,000-hour	(6) ____
5	LOI	Prec. amt.	Woody	(7) ____
6	BI	LAL	Herb	(8) ____
7	FLI			(9) ____

If you wish to see the variable tabulated or graphed, code its number in the correct column; otherwise, leave the column blank.

4 **Seasonal graphs**? "T" = yes, "F" = no. (10) ____

5 **Seasonal tables**? "T" = yes, "F" = no. (11) ____

6 Averaging periods for tables and graphs. Code with an odd number, 01-31 only. (12-13) ________

7 Graph individual years? "T" = yes, "F" = no. Remember that this **single year graph** feature may produce many pages of printout. It also turns off the **persistence probability tables** and the **BI seasonal severity list** and **summary table.** (14) ____

8 Persistence probability variable. Use one variable code from the list you chose in item 3. Code 0 if you do not wish to receive the **persistence probability table**. (15) ____

9 Select up to six upper boundaries for your persistence probability variable. (FIRDAT will do this for you if you place a variable code in column 45 of lead card two.) The boundaries are entered in ascending order, right justified.

(16-18) ____________
(19-21) ____________
(22-24) ____________
(25-27) ____________
(28-30) ____________
(31-33) ____________

10 **BI seasonal severity list** and **summary table?** "T" = yes, "F" = no. (34) ____

11 Enter the 90th percentile BI value here. Leave blank if you are combining SEASON with a FIRDAT run. (Round off BI value, no decimal point, right justify.) (35-37) ____

12 If you want to compare BI seasonal severity with different average values for the departures and number of days, enter the average yearly departure, including the decimal point, in columns 38-42, and (38-42) ____________

enter the average yearly number of days over the percentile in columns 43-47. Leave columns 38-47 blank unless you want this feature. (43-47) ____________

Note: You may have up to three SEASON cards in each run. To turn off SEASON, code a "3" in card column 1 and leave the rest of the card blank.

D.—FIRINF Control—Lead Card Four

ITEM DESCRIPTION AND CARD COLUMN(S)

1 Card number (1) ______

2 **Adjective class matrix**? "T" = yes, "F" = no. If "T" is coded in column 2, "F" must be coded in column 3. (Both columns 2 and 3 may be false.) (2) ______

3 **Precautions class matrix**? (See above.) (3) ______

4 Variable to be used for the table columns. Choose from the following list:

Code Variable
1 = IC
2 = SC
3 = ERC
4 = HCOI
5 = LOI
6 = BI
7 = FLI

(4) ______

5 Code up to 10 upper boundary values for the table columns.

(5-7) ______________ (20-22) ______________
(8-10) ______________ (23-25) ______________
(11-13) ______________ (26-28) ______________
(14-16) ______________ (29-31) ______________
(17-19) ______________ (32-34) ______________

6 Choose another variable from the list in item 4 for the table rows. (35) ______

7 Code up to 10 upper boundary values for the rows.

(36-38) ______________ (51-53) ______________
(39-41) ______________ (54-56) ______________
(42-44) ______________ (57-59) ______________
(45-47) ______________ (60-62) ______________
(48-50) ______________ (63-65) ______________

Note: This card may be repeated up to three times. Turn FIRINF off by coding card columns 2 and 3 false and leaving the rest of the card blank.

APPENDIX II.—OUTPUT PAGE ESTIMATOR

FEATURES	PAGES	TOTAL PAGES*
1) **Header page**	1 page per combination	5
2) **Daily list** (if T)	Total days/50	60
(if A)	Total days x combinations/50	300
3) **Annual summary**	Years x combinations	100
4) **Cumulative frequency**	2 pages x combinations xfrequencies selected	110
5) **SEASON graph**	4 pages x combinations x variables selected x SEASON cards	420
6) **SEASON tables**	3 pages x combinations x variables selected x SEASON cards	315
7) **Single year graph feature**	Multiply item 5 or item 6 x years	8,400 (5) 6,300 (6)
8) **Persistence probability**	6 pages x combinations x SEASON cards	90
9) **BI seasonal severity**	5 pages x combinations	45
10) **FIRINF**	22 pages x combinations x FIRINF cards	330

*With five combinations, 20 years (3,000 days), and everything turned on (three SEASON and three FIRINF cards), the output would be 15,545 pages.

Note: When the **single year graph** feature is on, FIREFAMILY produces a great deal of paper even though it turns off everything else in SEASON.

APPENDIX III.—JOB RUNSTREAMS AND PASSING FILE FORMAT

The Fort Collins Computer Center, home of FIREFAMILY, is equipped with a UNIVAC 1100 series computer and the EXEC 9 operating system. Changes in FCCC equipment or systems may make the following examples and job instructions obsolete.

The first part of Appendix III will help your computer specialist set up the job-control language needed to execute FIREFAMILY at FCCC.

We have included two typical runstreams. The first shows how to access the National Fire Weather Data Library (see Furman and Brink 1975) to obtain historical weather records, execute the FIREFAMILY program, and catalog the **passing file**. Our second example shows how to use a previously created **passing file** as input to the FIREFAMILY routines SEASON and FIRINF.

Appendix IIIb shows the format of the **passing file**.

A.—Running FIREFAMILY Using Historical Weather Data

```
@RUN,P/B YOUR ID,ACCOUNT NUMBER,QUALIFIER,TIME,PAGES
@SYM PRINT$.,,PR .  (Send the output to a high-speed printer.)
@ASG,A FIREDATALIB*PROGRAMS.
@ASG,A FIREDATALIB*21-24. . (Get the fire weather tape.)
@ASG,UP YOUR-DATA. . (Unconditionally catalog the weather holding file.)
@USE 2.,FIREDATALIB*21-24.
@USE 15.,YOUR-DATA.
@XQT FIREDATALIB*PROGRAMS.GETDATA2 . (Get the required weather data.)
  24010700  24010799
@EOF
@ASG,UP PASS. .   (Unconditionally catalog the passing file.)
@USE 7.,YOUR-DATA. .  (Use the data just obtained from the NFWDL.)
@USE 9.,PASS.
@USER*JOB.IDENT MAIL TO     ,FIREMANAGER ,SOMEPLACE MO,87603
  (Use for Fort Collins  printing.)
@HDG,N X.M,66,0,0 .  (Turn off normal page control.)
@XQT NFDR78*FIREFAMILY.FIRDAT1 .  (Execute the program.)
1KOOTENAI NF LIBBY MONTANA       240107 207049C2A20099050909TTTTTTTTTFFT
2 1.00 12 1206010910                             69097
311234567TT01F6
4TF
@SAVE QUALIFIER*PASS.,810301  . (Save the passing file until  March 1, 1981.)
MY FIRDAT PASSING FILE'S NAME
  (The qualifier must be explicitly specified and the above file description
   line must be included.)
@FIN
```

RUNNING FIREFAMILY USING A PREVIOUSLY CREATED PASSING FILE

```
@RUN,P/B YOUR ID,ACCOUNT NUMBER,QUALIFIER,TIME,PAGES
@SYM PRINT$.,,PR .  (Send the output to a high-speed printer.)
@ASG,A QUALIFIER*PASS. . (Assign the previously created passing file to this run.)
@USE 9.,QUALIFIER*PASS.
@USER*JOB.IDENT MAIL TO     ,FIREMANAGER ,SOMEPLACE MO,87603
  (Use for Fort Collins printing.)
@HDG,N X.M,66,0,0 . (Turn off normal page control.)
@XQT NFDR78*FIREFAMILY.FIRDAT1 .  (Execute the program.)
1KOOTENAI NF LIBBY MONTANA       240107 207049C2A20099050909FFFFFFFFFTFF
2 1.00 12 1205010910                             69097
311234567TT01F3
4FT
@FIN
```

(Parenthetical expressions explain each job-control card.)

UPPER CASE ITALICS indicate where coding will differ from run to run.

B.—Running FIREFAMILY Using a Previously Created Passing File

The **passing file**, a product of FIRDAT, is used to transfer weather, fuel moistures, and NFDRS components and indexes from FIRDAT to SEASON and/or FIRINF. If retained after the FIRDAT run, this computer readable file can be reused as input to SEASON and/or FIRINF. It may also be used as input to future analysis programs.

The **passing file** contains three kinds of records: a flag indicating a change of station or change of station parameters, a header reporting the station parameters, and the daily data values.

FORMATS

RECORD ONE, Flag:

Item	Columns	Type[2]
Flag: 999999999999	1-12	N

RECORD TWO, Header:

Item	Columns	Type
Administrative owner	1-12	A-N
Station name	13-32	A-N
Station number	33-38	N
Elevation	39-43	N
Latitude	44-45	N
Fuel model	46	A
Slope class	47	N
Herbaceous type	48	A
Climate class	49	N
Julian green-up date	50-52	N
Run date	53-64	A-N
Julian first freeze	65-67	N
Beginning and ending years	68-71	N

RECORD THREE, Daily Data:

Item	Columns	Type
Station number	1-6	N
Date	7-12	N (year-month-day)
Julian date	13-15	N
Processing option	16	N
State of weather	17	N
Temperature	18-20	N
Relative humidity	21-23	N
Wind direction	24	N (8 point compass)
Wind speed	25-27	N
Max temperature	28-30	N
Min temperature	31-33	N
Max relative humidity	34-36	N
Min relative humidity	37-39	N
Precipitation duration	40-41	N (hours)
Precipitation amount	42-45	N (10.94 written as 1094)
Lightning activity level	46	N
Human-caused risk	47-49	N
1-hour fuel moisture	50-52	N (14.5 written as 145)
10-hour fuel moisture	53-55	N (14.5 written as 145)
100-hour fuel moisture	56-58	N (14.5 written as 145)
1,000-hour fuel moisture	59-61	N (14.5 written as 145)
Woody moisture	62-64	N
Herbaceous moisture	65-67	N
Blank	68-69	
Ignition component	70-72	N
Spread component	73-75	N
Energy release component	76-78	N
Human-caused fire occurrence index	79-81	N
Lightning-caused fire occurrence index	82-84	N
Burning index	85-87	N
Fire load index	88-90	N

---

[2] A-N = Alpha-numeric;
N = Integer; A = Alpha

APPENDIX IV.— ABBREVIATIONS AND GLOSSARY

Abbreviations

BI	—Burning index.
ERC	—Energy release component
FLI	—Fire load index.
HCOI	—Human-caused fire occurrence index.
HCR	—Human-caused risk.
IC	—Ignition component.
LAL	—Lightning activity level.
LOI	—Lightning fire occurrence index.
LRS	—Lightning risk scaling factor.
NFDRS	—National Fire-Danger Rating System.
SC	—Spread component.
TL	—Timelag.
1-hr TL FM	—1-hour timelag fuel moisture content.
10-hr TL FM	—10-hour timelag fuel moisture content.
100-hr TL FM	—100-hour timelag fuel moisture content.
1,000-hr TL FM	—1,000-hour timelag fuel moisture content.

Glossary

Adjective class matrix—The table that combines the manning classes (usually based on the BI) with the IC to specify the standard levels of fire danger for public information.

Burning index (BI).—An NFDRS value related to the contribution of fire behavior to the effort of containing a fire. The BI measures fire intensity (BI = 10 x flame length).

Components of the NFDRS.—Components include ignition, spread, and energy release.

Cumulative departure.—The sum of the daily departures (usually for a year).

Cumulative frequency.—The sum of all of the frequencies up to and including this one.

Daily departure.—The numerical difference between the daily value of the variable and the 90th percentile value of that variable when the daily value is greater than the 90th percentile value.

Energy release component (ERC).—A number related to the available energy (Btu) per unit area (square foot) within the flaming front at the head of a fire.

FIRDAT.—A routine of FIREFAMILY that combines historical weather records with the equations of the NFDRS to produce frequency distributions of the NFDRS indexes and components.

Fire-danger rating area.—A geographical area within which the fire danger can be assumed to be uniform. It is relatively homogeneous in climate, fuels, and topography.

FIREFAMILY.—A computer program that uses historical weather data for fire planning. Its three major routines are FIRDAT, SEASON, and FIRINF.

Fire load index (FLI).—A rating of the maximum effort required to contain all probable fires occurring within a rating area during the rating period.

Fire season.—A period during which weather and fuels are conducive to wildfires. (Also, see split fire season.)

FIRINF.—A routine of FIREFAMILY that uses data from FIRDAT to create tables of combinations of two NFDRS indexes and components.

Frequency (also relative frequency).—Proportion of occurrences of a value at a particular numerical level compared with all occurrences.

Fuel model.—A simulated fuel complex for which all the fuel descriptors required by the mathematical fire spread model have been specified.

Fuel moisture content (also fuel moisture) (FM).—The water content of a fuel particle expressed as a percent of the ovendry weight of the fuel particle. The six NFDRS fuel moistures are woody, herbaceous, 1-hour, 10-hour, 100-hour, and 1,000-hour.

Header page.—The first page of output, which repeats the user-supplied lead card information.

Herb.—A plant that does not develop woody, persistent tissue but is relatively soft or succulent and sprouts from the base (perennials) or develops from seed (annuals) each year. Included are grasses, forbs, and ferns.

Herbaceous fuels.—Undecomposed material, living or dead, derived from herbaceous plants.

Human-caused fire occurrence index (HCOI).—A rating value formed by combining HCR with today's IC. It is related to the expected number of reported wildfires in the rating area.

Human-caused risk (HCR).—A number related to the expected number of human-produced firebrands capable of starting fires that a rating area will be exposed to during the rating period.

Human-caused risk scaling factor (HCRSF).—A number relating human-caused fire incidence to the IC on a rating area. The factor is a statistic based on 3 to 5 years of fire occurrence and fire weather data that adjusts the prediction of the basic human-caused fire occurrence model to fit local experience.

Ignition component (IC).—The rating of the probability that a firebrand will cause a wildfire requiring suppression action.

Indexes of the NFDRS.—Human-caused fire occurrence, lightning-caused fire occurrence, burning, and fire load.

Lead card.—The user-supplied part of the job runstream which provides information and chooses options for the FIREFAMILY program.

Lightning activity level (LAL).—A numerical rating of 1 to 6, keyed to the start of thunderstorms and the frequency and character of cloud-to-ground lightning, forecast or observed on a rating area during the rating period.

Lightning fire occurrence index (LOI).—A numerical rating of the potential occurrence of lightning-caused fires.

Lightning risk (LR).—A number related to the expected number of cloud-to-ground lightning discharges capable of starting fires that a rating area will be exposed to during the rating period.

Lightning risk scaling factor (LRS).—A factor derived from local thunderstorm and lightning-caused fire records that adjusts the predictions of the basic lightning fire occurrence model to local experience. It accounts for factors not addressed directly by the model such as susceptibility of local fuels to ignition by lightning, fuel continuity, topography, and regional characteristics of thunderstorms.

Manning classes (also manning levels).—The minimum strength of forces which an agency plans to activate at each level of fire danger.

Matrix.—As used in this paper, another word for table.

Passing file.—A product of FIREFAMILY that saves FIRDAT data for later use with SEASON and/or FIRINF.

Persistence probability.—As used in this paper, the fraction of the time that weather will remain the same 2 days in a row.

Precautions class matrix.—A table (used principally in the USDA Forest Service Region 6, the Pacific Northwest) that uses the ERC or the BI with the IC. One use of the precautions class matrix is to regulate industrial forest usage.

Relative frequency.—See frequency.

Runstream (also job runstream).—Series of control cards used at Fort Collins to run FIREFAMILY.

SEASON.—A routine of FIREFAMILY that uses FIRDAT's results to tabulate and graph one NFDRS index, component, or fuel moisture at a time to show seasonal weather patterns.

Split fire season.—Two or more periods of many wildfires separated by a period of few fires.

Spread component (SC).—A rating of the forward rate of spread of a head fire expressed in feet per minute.

Variable.—In this paper, any of the NFDRS indexes or components. In FIRDAT and SEASON, fuel moistures are also considered variables.

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Main, William A.; Straub, Robert J.; Paananen, Donna M.
FIREFAMILY: Fire planning with historic weather data. Gen. Tech. Rep. NC-73. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1982. 31 p.

This user's guide will help fire managers interpret the output from FIREFAMILY, a computer program that uses historic weather data for fire planning. The guide describes options within the program and explains various tables and graphs necessary for planning. It also provides details which computer specialists need to run the program.

KEY WORDS: Fire weather, fire danger, National Fire-Danger Rating System

United States Department of Agriculture

Forest Service

North Central Forest Experiment Station

General Technical Report **NC-74**

Black Walnut for the Future

CLEMSON UNIVERSITY
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PREFACE

Interest in planting and managing black walnut trees continues at a high level. The premium prices paid for walnut logs, the value of the nut crop, and the satisfaction derived from tending trees all contribute to this interest and to the resultant need for information on how to grow walnut trees. A workshop on walnut culture held in 1966 focused on the then existing information and identified some of the research needed to obtain additional knowledge. A second symposium in 1973 continued this process, and in 1981 a third symposium was held to summarize current information on walnut and to establish the direction of research for the next several years. These proceedings are the product of the 1981 symposium.

The symposium resulted from the same cooperative effort that proved so effective for its predecessors. Primary among these cooperators were Purdue University, the Walnut Council, North Central Forest Experiment Station, and the Northern Nut Growers Association. Numerous other institutions, industry representatives, and private individuals contributed significant amounts of time and effort. This cooperation produced not only a sucessful symposium but, of equal importance, these proceedings.

The proceedings bring together in one publication much of the currently available information needed to successfully grow black walnut; much of this information is new or has been refined since the previous symposium. The 1973 proceedings served as a guide for several thousand people. We expect that these proceedings will likewise serve as the basis for management recommendations during the next decade.

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THE WALNUT COUNCIL IN PERSPECTIVE[1]

Gary G. Naughton[2]

This twelfth annual meeting of the Walnut Council is truly an auspicious occasion. We have already survived almost 4 times as long as the average new business enterprise in America, our numbers are still growing, and we have a right to be truly proud of our accomplishments.

Those of us who have had the good fortune to have been part of this Council since its beginning at Indianapolis in 1970 have had the opportunity to see, first hand, the finest groves of walnut trees on the face of this earth. Not only seeing walnut trees in all their glory, but getting to know them and the people who own, plant, manage, harvest, and use walnut trees are the things which make the walnut Council go.

The Walnut Council is unique among organizations. Founded on the principle of sharing knowledge and experiences for the benefit of society, our membership is open to anyone with an interest in walnut. We are neither solely scientific nor technical nor educational nor recreational nor financial in our interests. Yet, we are all of these things in good measure. Landowners, scientists, educators, manufacturers, and speculators all form important parts of our Council. And all contribute to the benefit of the group.

Our significant strength is that we challenge each other. We have the audacity to ask the hard questions, the charity to share our ideas with others, and the grace to accept criticism--all of which are part of every meeting we have ever held.

From the beginning, the members of this Council have expressed an attitude of friendly competition. Remarks such as "It's too bad you folks can't grow as good walnut in your part of the country as we do in my area" are accompanied with the unspoken belief that even poor walnut trees are good property.

And, the competition will always be friendly because we know that--even in the face of our past 12 years of organized effort--walnut trees are becoming increasingly scarce. The strength of consumer demand for walnut products continues to assure us that our only true competition in this business is with time and nature. We are truly fortunate that we need not hold back, selfishly, from helping each other. Our combined effort to overcome common problems is the source of our strength.

This is the Third Walnut Symposium. Each in its turn has served to focus on the current "State of the Art" in walnut culture and management. And, as you shall see, each has become progressively more fruitful in bringing us toward our goal of improving the production of walnut and its many products. The proceedings from the 1966[3] and 1973[4] symposia, along with those from this year are an invaluable collection of the best information available for persons interested in walnut.

We still have a serious task ahead of us. Many of the problems we experience in our personal endeavors with walnut are still unsolved and pose a challenge to us for the future.

PROBLEMS

We are still looking for the magic formula to solve the two biggest questions that foresters the world over must constantly address. They are: 1) "How many trees should we plant?", and 2) "When should we harvest?"

I can assure you, today, that the best answers to these questions will never be the same for all of us. We still find that it all depends on "the situation and the terrain."

---

[1] Paper presented at the Black Walnut Symposium, West Lafayette, Indiana, August 10-14, 1981.

[2] Gary G. Naughton, Chairman Assistant State Forester, Kansas.

[3] "Black Walnut Culture", proceedings of a walnut workshop, Carbondale, Illinois, August 2-3, 1966. USDA Forest Service North Central Forest Experiment Station. (This workshop held before start of the Walnut Council.)

[4] "Black Walnut as a Crop", proceedings of the black walnut symposium, Carbondale, Illinois. August 14-15, 1973, USDA For. Serv. North Central For. Exp. Stn., Gen. Tech. Rep. NC-4, p. 97-100.

It is quite possible to start with 1,000 or more seedlings per acre and plan the final harvest for the age of 200 years, producing as a result exceptionally high quality veneer log which would be in demand throughout the world. But we also know that there is good profit in stands which start at 200 to 300 trees per acre and are at final harvest stage in 60 to 80 years.

It is my opinion that we need both styles of management systems to complement each other. The longer rotations fit nicely into forest management systems on public lands, while the shorter rotations are a matter of economic practicality and reality on private lands. In any case, walnut management requires a profound and unwavering sense of optimism for the future.

One of the first external problems addressed by this Council was the need for a realistic and consistent National policy on the export of raw walnut logs into the International market. This has proved to be a two-edged sword--an enigma of gigantic proportions. As in most situations of this sort, idealism gets totally entangled and confused with reality. From the beginning there was general recognition that a problem existed in this area, but no agreement on how to solve it.

Ideally, the valuable natural resources of a nation (walnut in this case) serve that nation best when they are exported as components of finished products rather than as raw materials. But market forces are fickle. For example, in International markets there are frequently substantial import duties levied on consumer goods--because all nations recognize the differences in capital flow and employment opportunities represented by the contrast between a log and a piece of furniture.

Human nature also dictates that the landowner offering timber for sale is interested in getting the best cash price, sometimes in spite of the nationality of the buyer.

I believe that this problem has been more or less solved by default. The major walnut log processing companies--many of whom have had active membership in this Council since the beginning--have developed their own international markets and have substantially increased world demand for walnut products by introducing them to new customers in foreign countries.

The result is that more partially processed material is being exported than before and this provides more jobs at home. The situation has evolved to the point now that the current slump in walnut prices is more a function of the strength of the U.S. dollar against other currencies than it is a function of consumer demand.

ACCOMPLISHMENTS

At the risk of overlooking something of significance in terms of this Council's accomplishments, I will address only two. Naturally, it is my conclusion that these two accomplishments are the most significant.

One is the fact that, under the crusading leadership of Don Gott, Council member and former Executive Director of the Fine Hardwoods--American Walnut Association, we obtained consumer protection labelling restrictions for walnut products on the retail market.

These attractive tags and labels have since become a hallmark of quality and reliability for the American consumer. It is my understanding that the FH-AWA office at Indianapolis dispenses over 1/2 million of these labels annually. (See Article in 1973 Symposium Proceedings, page 23).

The net effect of this accomplishment is to protect and stabilize the market of walnut products, and consequently the producers from farm to mill to factory. To paraphrase a well-known commerical advertisement--"When you are number one you are prouder."

The second and most significant accomplishment I want to recognize is the communication forum that this Council has established. Although imperfectly developed this is our greatest asset. Because of the unique structure of the Walnut Council--a fact already discussed--the development and transfer of knowledge and information is rapid and continuous.

Landowners have the opportunity to meet and question research and industry interests face-to-face on a person-to-person basis. When the links of the chain from production, research, industry, technology, and finance know each other as individuals true communication exists.

But, I want to offer a word of caution here. Members of the Executive Committee--past, present, and future--have been and will continue to receive mail and telephone inquiries relating to walnut from people outside their normal sphere of operation and influence. We must not forget our obligation to refer such requests to appropriate people closer to the situation. These might be consultants, service foresters, extension specialists, researchers, or industry people. The proper function of the Council in this respect is to put the request into the best hands available not to directly respond to requests. Except for general inquiries which can be handled by sending the appropriate printed information, it is folly for someone in Kansas to try to offer advice to a walnut grower in Indiana.

THE FUTURE

I have spent most of this period talking about the past and I don't apologize for that. Perspective depends upon looking back to see where you have been so that you can decide where you ought to go in the future. So, having been there, where do we go next?

I believe that, first of all, the Walnut Council is a viable organization with a long future ahead of it. This assumption leads to the following suggestions as goals:

1. We should plan now for another symposium, to be held sometime between 1988 and 1990 . . .

2. We should make a strong effort to triple our membership by 1985 (approximately 2,000 members), and work hard to reach 5,000 by 1990.

3. We should seriously consider establishing some type of endowment fund within the Council for the purposes of financing research and/or educational efforts on the broad spectrum of interest relating to walnut.

4. We should begin, at the first opportunity, to aid in the establishment of state walnut associations, patterned after the Council, but affiliated only to the extent they wish to formalize.

5. We should plan now to hire a part-time Executive Director in about 1990 and to have this position become full-time by about 1995.

There is our challenge. Nothing remains constant very long. We must forge ahead or fade into obscurity.

WALNUT IN PERSPECTIVE: THE CHALLENGE CONTINUES[1]

R. Max Peterson[2]

I congratulate you on your joint meeting, and on the extensive program which you have underway. The wealth of information exchanged at this meeting is impressive, and something you can all be proud of.

This forum continues to serve as the catalyst for excellence in cooperation among public agencies, colleges and universities, industry, and landowners. That type of cooperation existed before this Council was formed. But it's better because of it.

When he invited me here, Gary Naughton made it a point to tell me that former Chief Ed Cliff keynoted the first of these walnut conferences in 1966--before the Walnut Council was even formed . . . and that John McGuire--who was Chief just before me--gave the keynote speech at the second of these conferences.

So I'm pleased to be at Purdue, and to keynote this third walnut conference . . . and the second joint meeting of your two groups.

But before I left the office to come out here, I was discouraged to look at some of the walnut data assembled by our forest survey staff.

Despite two of these conferences in the last 15 years . . . which focused on what needed to be done about the problem of declining walnut quality and quantity . . . the problem doesn't seem to be getting any better. At least, not very fast.

As a generality, we have a lot of hardwood timber. Anyone driving through the East can attest to that. In some parts of the Eastern United States it's difficult to find markets for a number of hardwoods. Supply significantly exceeds demand. Growth is much greater than removals. We have an underutilized resource in hardwoods in general.

But, as you know, the situation is quite the opposite for black walnut and other fine hardwoods. We have an overutilized resource. Demand has been greater than supply for several years. And that gap is projected to widen over the next 50 years.

Yet, to meet that demand, we're seeing only a slight increase in walnut growing stock, nationwide . . . and a significant decrease in inventories for trees larger than 15 inches in diameter.

In some states, this decrease in walnut inventories is quite significant. In Iowa, for example, walnut growing stock inventories have shrunk by more than a third in twenty years . . . and sawtimber inventories have been reduced by more than half.

In Missouri, where I grew up, black walnut was a well-known and respected tree that was valued, not only for the wood it produced, but also for the nut itself. The inventory of walnut growing stock in Missouri has shrunk by 3 percent between 1959 and 1972 . . . sawtimber inventories have diminished by 9 percent.

Now let's admit it . . . that's discouraging. But all of that bad news doesn't reflect the work you've been doing.

Jack Spencer of our forest survey staff at North Central Station tells me that there's a lot of walnut planting going on . . . but that the trees aren't yet big enough to show up in the inventory figures.

And judging by the program here, it's quite likely that those walnut trees will grow faster, be better protected, produce more nuts, be better utilized, and be worth a lot more than the generation of walnut trees we've been working with in the past.

I say that because we've learned a lot about growing walnut over the past 20 years.

We've learned a lot about defining suitable walnut sites. Enough to establish a reliable system for site evaluation.

We've come to realize the beneficial effects of weed control on walnut growth.

---

[1] Paper presented at the Black Walnut Symposium, West Lafayette, Indiana, August 10-14, 1981.

[2] R. Max Peterson, Chief of the Forest Service, United States Department of Agriculture, to the joint meeting of the Walnut Council and Northern Nut Growers Association, Purdue University, Lafayette, Indiana, August 11, 1981.

We've learned a great deal about the possibilities of interplanting walnut with nitrogen-fixing trees and shrubs.

Through Bry Clark's early research, we've learned that thinning to favor walnut in natural stands holds good potential for accelerating the growth of the remaining trees.

And through the work of Walt Beinecke, Dave Funk, Calvin Bey, and others we've come a long way in walnut tree improvement. We've defined preliminary seed collection zones and established improved seed sources. Three states have initiated walnut tree improvement programs.

Each of these advances--and many others I haven't mentioned--can lead to greater walnut production. There's ample opportunity for even further advances in most of these important areas, too.

The record of research accomplishment and research cooperation in walnut culture and utilization is one which we can all be proud of.

But developing all of that knowledge will not, by itself, solve the black walnut shortage problem . . . the problem of declining quality and increasing cost.

That problem can be moderated in the short run, but not solved, through improved utilization. That aspect of your work will become even more important as walnut prices increase.

A longer-term solution will come, however, only to the extent that we put that knowledge to work on a wide basis . . . that landowners and forest managers recognize the opportunities in walnut, and actively manage for it.

That's how we are challenged in the next two decades . . . in motivating and informing landowners. It's a challenge which Ed Cliff laid out at the first walnut workshop in 1966 . . . and which John McGuire reiterated and emphasized in 1973.

That challenge continues today . . . because we need to devote much more energy and skill to getting walnut management started on a significant scale. We need to motivate landowners to manage for walnut. And we need to give them the information they need to do it right . . . information such as that presented at this conference.

We want to do our share on the National Forests, by managing appropriate sites for high-quality hardwoods. Growing walnut in natural stands over long rotations is particularly well-suited to multiple use management. So it fits well into what we are trying to do on the Eastern National Forests.

Many of these National Forests have active black walnut programs, particularly in tree improvement and plantation establishment.

For example, we are cooperating with the Tennessee Valley Authority, and with the states of Indiana, Kentucky, and Tennessee, in provenance and progeny testing. These tests involve several hundred selections over much of the range for Black Walnut. If successful, several of these experimental outplantings on the National Forests will be converted to first-generation seed orchards.

We have been disappointed with the results from introducing walnut into cutover stands and with establishing black walnut on abandoned fields. Therefore, we will no longer make special efforts to introduce walnut as a component in mixed stands until we have better prescriptions for doing it.

However, we have established nearly 3,000 acres of black walnut plantation on the National Forests over the past 10 years. Some of the earlier plantations were put on poor sites. Some of the others apparently didn't receive proper site preparation or follow-up treatments.

Anyway, the results of these plantations can't all be considered successful, though we're generally pleased with the plantation effort.

We will continue to establish black walnut plantations on suitable sites. Most of these will be on the Daniel Boone, Wayne-Hoosier, Shawnee, Mark Twain, and Monongahela National Forests.

And where it occurs in natural stands, we will continue to manage and favor black walnut as a component of mixed stands.

We don't have a lot of sites on the National Forests which are suitable for intensive walnut management. However, we will use those that are there. Because, just as you're interested in increasing black walnut production, we're interested in having the National Forests do their share.

However, to change the focus of our attention, let me quote John McGuire from his keynote to the 1973 walnut conference:

He said that "the success or failure of our program to increase production of walnut and other fine hardwoods will depend on the degree of participation by nonindustry private landowners who own 70 percent of the hardwood sawtimber. Their land includes most of the productive walnut sites and nearly all the growing stock. We need to stimulate greater interest among the small private landowners in developing maximum productivity of their forest lands."

How well are we doing with these landowners?

Not as well as we should be.

Yet, it seems to me that there are several factors--such as the current combination of market, incentives, and national mood--which should give landowners unprecedented motivation to grow walnut on appropriate sites.

First, the nature of the tree is such that it can be managed in harmony with nearly any sort of landowner objective short of wilderness.

Second, there appears to be an emerging interest in trees which produce nuts which people can eat.

Third, the outlook for walnut shows future demand exceeding supply, and continued high prices.

Fourth, it seems to me that the increased use of wood for energy has a lot of landowners coming to realize the value of their woodlots . . . first for firewood, then for other products as well.

But there's a danger there, too. The same axe that's used to thin a woodlot . . . can be used to wreck it as well. We must educate landowners to recognize high-value hardwoods and leave them to grow to maturity.

Fifth, as the Forest Service and cooperating universities get further along with their Eastern Hardwood Initiative, it may well open up some additional opportunities to manage for fine hardwoods . . . walnut included. This Initiative is a broad-scale effort to find some better uses and better markets for all eastern hardwoods, particularly where they can take over some of the uses which are placing such demand on softwoods. It will probably have some good effects upon the supply of fine hardwoods as well.

And sixth, let me briefly note--since you have a broader discussion scheduled for your program tomorrow--that in recent years, Congress has legislated a comprehensive package of tax incentives and other forms of encouragement to help landowners quickly recover many of their costs.

The combination of all of the factors I've just cited indicate an especially auspicious time for walnut management on private forest lands.

But we've got to point out those opportunities.

We have to speak from the economic point of view--to let the landowner know that walnut management can pay if it's done right, and on the right sites.

And after spending these several days at Purdue . . . talking with each other . . . we've got to go out and talk with the landowner.

That challenge will always be with us.

AMBROSIA BEETLES IN YOUR BLACK WALNUT PLANTATION--
HOW SERIOUS ARE THEY?

Barbara C. Weber

Abstract.--The life history of Xylosandrus germanus and its effects on black walnut trees were studied from 1976 to 1980 in two plantations, one in North Carolina and one in Illinois. X. germanus has two generations per year with the heaviest attack period occurring in May and June. Signs and symptoms of attack include pinholes, basal sprouts, wilted leaves, and top dieback. Although tree survival is little affected by X. germanus attacks on black walnut, growth losses are potentially serious depending on the age of the trees when attacked and the management goals of the plantation. Some management and silvicultural control recommendations are included.

At the last Black Walnut Symposium in 1973, one of the insect problems discussed was an imported ambrosia beetle, Xylosandrus germanus (Blandford), that was associated with an unexplained dieback of young black walnut trees (Juglans nigra Linnaeus) in Illinois and Indiana. At that time, little was known about the beetle, but since then we have learned much about its life history and about the damage it does to black walnut trees. The purpose of this paper is to briefly summarize what we have learned about the biology of X. germanus, to describe the effects of attack on black walnut trees, and to recommend some ways to reduce the damage by this insect.

Much of the information presented in this paper comes from the study of X. germanus from 1976 to 1980 in two black walnut plantations. One plantation is located in McDowell County, North Carolina; the approximately 12 acres (4.9 hectares) were planted in 1973 and were attacked by X. germanus in spring 1976 and probably also in 1974 and 1975. Study of X. germanus was concentrated in a 5-acre (2.0 hectares) area located in the center of the plantation. The second plantation is located in Alexander County, Illinois; the approximately 7 acres (2.8 hectares) were also planted in 1973 but were not attacked by X. germanus until spring 1978.

SEASONAL LIFE HISTORY

Adult female X. germanus are black and approximately 0.1 inch (2.5 millimeters) long (fig. 1). Males are brown and about 0.06 inch (1.5 millimeters) long but are rarely seen because they do not fly and usually do not leave the gallery in which they live. The immatures are white, legless, and wormlike. They live in galleries made by the parent female in trees or other woody plants (fig. 2)

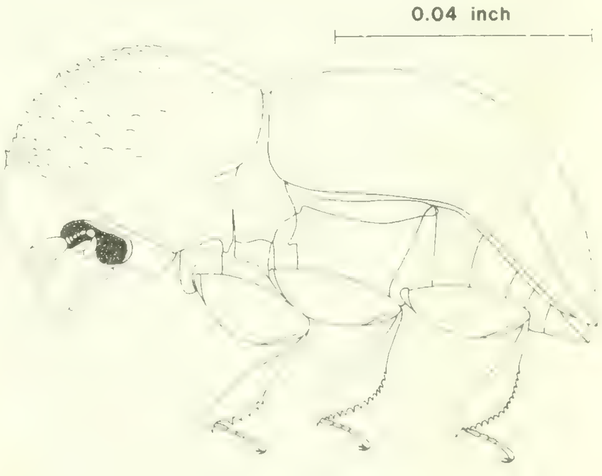

Figure 1.--Side view drawing of adult female X. germanus. (Drawing by S. W. Wilson.)

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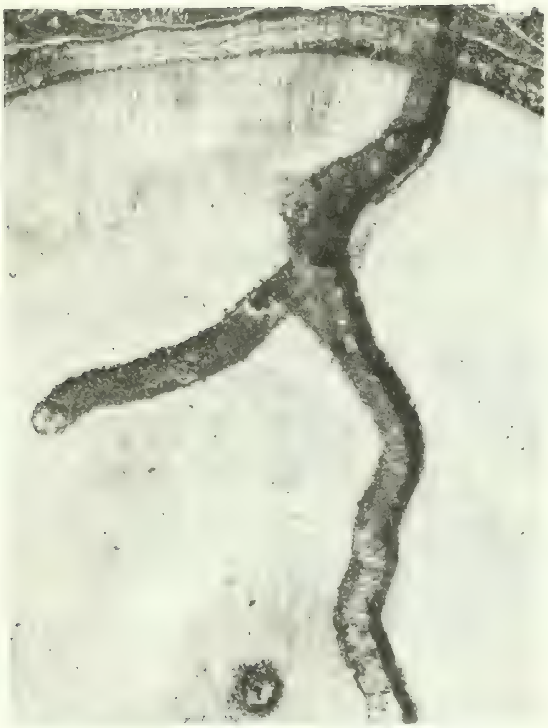

Figure 2.--Cross section of black walnut showing X. germanus gallery.

Adult females leave their overwintering sites in galleries at the bases of trees in March and April to search for new hosts. They fly primarily in the late afternoon and early evening. The beetles are slow, weak flyers and are, therefore, easily carried by the wind. In North Carolina, beetles in flight are present from late March until late August. In Illinois, beetles in flight are present from early April until early September. The average flying height is 4.9 feet (1.5 meters).

Once the beetles have located their new hosts, they bore into the tree and excavate the galleries in which they will lay their eggs and produce new adults. X. germanus apparently has two generations per year. In North Carolina, egg-laying occurs from early May to probably late June and from early June to early September. Adults of the first (summer) generation are present from mid-May to mid-July and those of the second (overwintering) generation from early July to the end of the season. In Illinois, egg-laying occurs from mid-May to early June and from late June to late July. Adults of the summer generation are present from early to late June and those of the overwintering generation from mid-July to the end of the season (fig. 3). The number of offspring per female ranges from 2 to 53.

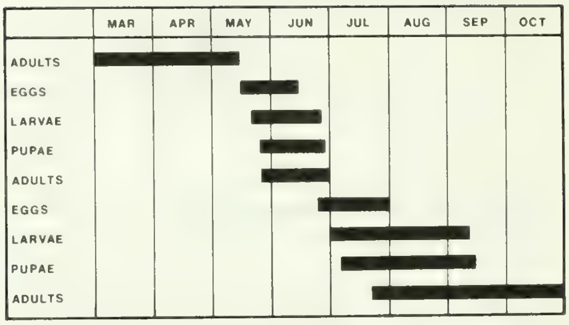

Figure 3.--Combined life history diagram of field-collected X. germanus in North Carolina and Illinois.

DISTRIBUTION AND HOSTS

The ambrosia beetle X. germanus was first reported in the United States in 1932 on Long Island, New York (Felt 1932). The beetle now occurs from New York to Missouri and from Louisiana to South Carolina. It attacks several kinds of woody shrubs and trees. In its native country of Japan, X. germanus attacks about 160 different species of plants (Nobuchi 1981). In the United States, Deyrup (1981) reported that in Indiana alone it attacks 20 different species of plants, including black walnut.

Miller (1973) and Kessler (1974) first reported attacks by X. germanus on black walnut in Illinois. Since then, many more damaged plantations have been found (table 1).

SYMPTOMS OF ATTACK

Signs and symptoms of X. germanus attack on black walnut trees include pinholes, basal sprouts, wilting leaves, and dieback. Pinholes are approximately 1/32 inch (1 millimeter) in diameter and are usually found in the lower trunk of attacked trees. Pinholes may also be found in branches that are within about 6.5 feet (2 meters) from the ground. Basal sprouts originate from the tree trunk at or below the groundline or they may occur above the groundline on the lower trunk. Wilting leaves and dieback may occur over the entire aboveground portion of the tree or on only one branch (fig. 4). Wilted and dead tops are the most easily detected symptoms of attack and can be found most frequently during May and June, the period of heaviest attack by X. germanus. Occasionally, cankers are also associated with beetle attacks.

Table 1.--Location, age, and height of plantation black walnut trees attacked by _X. germanus_

Location	Age when attacked[1]	Avg. ht. (ft.)[1]
ILLINOIS		
Alexander County	5	6.0
Jackson County	4	5.3
INDIANA		
Daviess County	-	-
Du Bois County	8	4.9
Fountain County	1	seedlings
Green County	-	-
Hamilton County	1	seedlings
Washington County	5	-
NORTH CAROLINA		
McDowell County	3	5.6
OHIO		
Scioto County	1-7	-
TENNESSEE		
Davidson County	2	3.9

[1] Dashed line means that the age and/or height of the trees at the time of attack were not known.

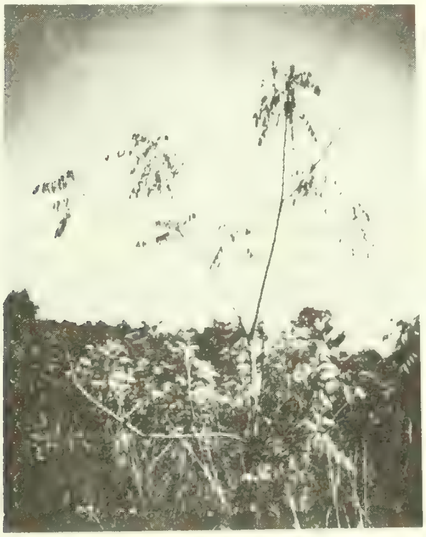

Figure 4.--Wilting leaves and top dieback of black walnut tree attacked by _X. germanus_.

Sometimes the only symptom of attack is the pinholes, but they are small and difficult to find. In the Illinois plantation, I found that the percentage of trees attacked by _X. germanus_ could be estimated from the percentage of trees that had wilted leaves or dead tops. Work is continuing to determine if this method of estimating the number of trees attacked by _X. germanus_ can be applied to all walnut plantations.

EFFECTS OF ATTACK

The effect of attack by _X. germanus_ on tree survival is less serious than first appearances show, although initial tree losses may appear high. Although the tops of attacked trees may die, the roots are usually still alive and send out sprouts that can replace the original tree. Approximately 350 of the 1,400 trees in the North Carolina plantation were attacked by early June 1976 and approximately 30 trees died. About 330 of the 2,220 trees in the Illinois plantation were attacked in spring 1978. Nearly 75 percent of the attacked trees suffered top dieback. All but four of the trees with top dieback eventually sent up basal sprouts from the still-living roots. If sprouts are pruned to one per root system, the original attacked trees can be replaced by fast-growing sprouts and thus reduce the effects of _X. germanus_ on tree losses in a plantation. However, the time required to cut and remove beetle-infested trees and to remove excess sprouts can be significant and costly.

The effect of beetle attack on tree growth is potentially more serious than on tree survival. In the Illinois plantation, the average height of trees attacked by _X. germanus_ in spring 1978 was 5.7 feet (1.7 meters) compared to 6.1 feet (1.9 meters) for trees not attacked. The average diameter at breast height (dbh) of trees attacked was 0.5 inch (1.3 centimeters) compared to 0.6 inch (1.4 centimeters) for trees not attacked. After three growing seasons, the average height of those trees attacked in spring 1978 was 8.5 feet (2.6 meters) compared to 9.8 feet (3.0 meters) for trees not attacked. Average dbh of attacked trees was 1.0 inch (2.6 centimeters) compared to 1.3 inches (3.3 centimeters) for trees not attacked. These comparisons show that _X. germanus_ apparently selected smaller trees and suggest that smaller trees may be more susceptible to attack than larger ones. Younger trees may also be preferred because all of the plantations in which we found _X. germanus_ were less than 8 years old when attacked. Black walnut trees older than 10 years or more than about 2.5 inches (6 centimeters) in dbh probably will not be attacked by X. germanus. It is not known whether the smaller trees in the Illinois plantation were attacked because they were less healthy than the larger ones or whether they were simply slow growers and were preferred by X. germanus because of their smaller size.

The comparisons of sizes of attacked and not attacked trees also show that the attacked trees, or their replacement sprouts, were not able to catch up in height and diameter growth, three growing seasons after attack, to those trees not attacked. The attacked trees may be compared to the coppiced trees studied by Schlesinger (1981). He found that 5 years after treatment (that is, removing the entire aboveground portion of coppiced trees and allowing one sprout to replace the original tree), coppiced trees were about 20 percent shorter in height and about 26 percent smaller in dbh than noncoppiced trees. Schlesinger (1981) also found that the older the tree at the time of coppicing, the less likely it would be able to catch up in size to noncoppiced trees. Trees coppiced when they were 2 years old were only about half a year "younger" in size at age 11 than same-age noncoppiced trees, but trees coppiced when they were 5 years old were 3 years "younger" in size at age 11 than same age noncoppiced trees. That is, trees coppiced at age 5 would have to grow for 3 more years after the harvesting of noncoppiced trees to equal the size of the noncoppiced trees. These findings suggest that trees attacked by X. germanus when they are younger (for example, 2 years old) will be closer in size at harvest time to trees not attacked, and, thus, more likely to be selected as harvest trees, than trees attacked by X. germanus when they are older (for example, 5 years or more).

The seriousness of growth losses due to X. germanus attack depends on the total number of trees attacked and the management goals for the plantation. If a large percentage of the trees has been attacked, the average tree size may be significantly reduced, as indicated in the Illinois plantation, and result in a longer time to final harvest of commercial-sized trees.

If management goals require that all plantation trees become final crop trees, every tree is important. No tree loss and little growth loss can be tolerated. Such situations may develop when few trees are planted originally. On the other hand, if more trees are planted initially than are needed for final crop trees, individual tree selections can be made periodically to keep the faster-growing, straighter trees and eliminate the slower-growing, less desirable ones. Under these more flexible management goals, most trees attacked by X. germanus that are not comparable in size to trees not attacked will probably be removed by harvest time.

Another factor in assessing the seriousness of X. germanus attack is the genetic background of the trees. The Illinois plantation was designed to compare growth characteristics of trees from different sources in six States--Arkansas, Illinois, Kansas, Kentucky, Missouri, and Tennessee. Kansas trees were attacked least frequently (2 percent) and Kentucky trees were attacked significantly more often than trees from any of the other sources (13 percent) (table 2). These results suggest that genetic variation in susceptibility to attack may be important. Further study in this area is needed.

Table 2.--Trees from each State attacked by X. germanus in spring 1978 in the Alexander County, Illinois, black walnut plantation

State	Total no. trees	% attacked
Arkansas	233	9
Illinois	261	7
Kansas	59	2
Kentucky	354	13
Missouri	159	5
Tennessee	928	7

An aspect of concern, however, is the planting of large numbers of trees from a few seed sources (a seed source refers to the parent tree) or grafted seedlings taken from only one or two trees if one or more of these seed sources or clones are susceptible to beetle attack. If the grafted portion is attacked and sprouts are produced by the root stock, the selected, superior growth characteristics or nut potential of the grafted portion are lost and the tree's value is reduced to that of a normal, nursery-run tree.

CONTROL RECOMMENDATIONS

Good management and silvicultural control practices may provide the best options for minimizing damage by X. germanus. Direct chemical control of the insects on walnut trees is not practical because the beetles spend most of their life cycle within trees where chemical sprays cannot penetrate. Treatment with systemic insecticides may be effective during the initial stages of attack, but no research has been done to test their effectiveness. Therefore, I recommend the following practices to reduce the effects of X. germanus on black walnut plantations.

1. Select planting sites that have deep, well-drained soils; if possible, have your local forester examine the site.

2. Plant trees at close spacing (e.g., 10 feet x 10 feet [3m x 3m]) to allow later thinning and selecting for the best trees.

3. Plant trees from several locations or seed sources to reduce the chances of severe losses if one or two seed sources are highly susceptible to X. germanus attack.

4. Manage the trees, especially during the first 10 years, with techniques known to promote rapid growth. Examples of such techniques would be weed control and interplanting with nitrogen-fixing plant species such as autumn olive.

5. Treat fresh hardwood stumps within a 1/4 mile (about 500 meters) radius of the plantation with diesel fuel or other stump treatment because X. germanus often live in stumps in cutover forested areas.

6. Remove affected trees from the plantation as soon as possible after attack by X. germanus, evidenced by wilting or dead tops. Destroy them to prevent population buildup within the plantation.

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VARIATION IN INHERENT DECAY RESISTANCE OF BLACK WALNUT[1]

John H. Hart[2]

Abstract.--Sapwood and heartwood from fast-growing black walnut decayed at the same rate as sapwood and heartwood collected from slow-growing trees. Based on results from 15 trees (three trees from each of five states) the sapwood was more decay susceptible than the heartwood. There were no significant gradients in decay resistance of the heartwood associated with radial or longitudinal position in the trunk. The heartwood of individual trees from the same site varied significantly in decay resistance. This variation is attributed mainly to genetic variability. Similarities in heartwood decay resistance between trees collected in different states suggest that site is not a major factor in determining decay resistance.

Considering that black walnut is one of our most desirable and valuable timber species, there is little information on the chemistry and durability of its heartwood. Almost all available material on walnut describes the heartwood as decay resistant (Scheffer and Cowling, 1966), but published data to substantiate this claim could not be located.

Individual trees of the same species may vary considerably in their decay resistance (Scheffer and Cowling, 1966). This variation mainly is controlled genetically rather than by differences among sites on which the trees developed. Decay resistance also varies among different parts of the same tree (Scheffer and Cowling, 1966). Research with other tree species has shown that decay resistance decreases progressively from the outer heartwood to the pith. Decay resistance of the outer heartwood decreases progressively from the base of the tree upward, whereas the opposite is true for inner heartwood. Variation in decay resistance between individual black walnut trees or within individual trees has not been investigated.

As walnut wood is used in products that are expected to last for years or even decades, the resistance of this wood to microbial deterioration of importance even though the wood is seldom used under conditions conducive to decay. How durable is black walnut heartwood and does this durability vary in the different geographical areas that it inhabits? Is the heartwood in one part of the tree more durable than in another part of the tree? Will heartwood from fast-growing, intensively managed trees be as durable as that from naturally-occurring trees? The purpose of this research was to collect data which would answer these questions.

MATERIALS AND METHODS

To determine the effect of growth rate of walnut on decay resistance, four trees with different rates of growth were sampled. Blocks 2 cm^3 were cut 5 m above ground from logs harvested in Lansing, Michigan. The number of annual rings per cm was determined for each block. Blocks were dried at 45°C for one week, weighed, steamed for 15 minutes, placed aseptically into decay chambers containing Coriolus vesicolor or Poria placenta for eight weeks (McNabb, 1958), removed, dried at 80°C for one week, and reweighed. Ten blocks were used from each tree, each wood type and for each decay fungus.

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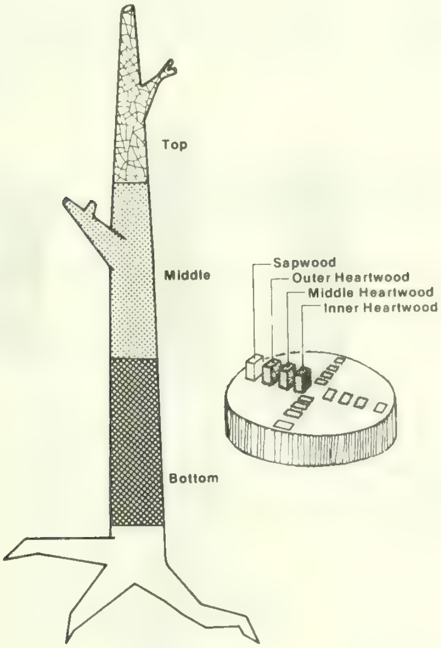

Figure 1.--Diagram of sampling procedure used in collecting blocks for decay studies. Samples were collected from the top, middle and bottom of the tree and, at each of these positions, from the sapwood and heartwood as illustrated.

To determine the variability in decay resistance throughout the range of black walnut and from different locations within a tree, three mature walnut trees were collected from five states: Kansas, Kentucky, Michigan, Pennsylvania and Wisconsin. All trees were dissected within one week of cutting except for the trees from Pennsylvania which were stored for 5 weeks at 0°C before sampling. Blocks 1.9 cm^3 were cut from three vertical positions from each tree: 0.5-1.0, 5-6 and 9-10 m above ground line. All samples had to be free from decay and defect; therefore, precise sample heights were impossible. At each vertical position cylinders 1.9 cm in thickness were cut. Blocks were cut from four radii so that there would be 4 sapwood, 4 outer heartwood, 4 middle heartwood and 4 inner heartwood blocks (fig. 1). Blocks from a given cylinder were used for one of the test fungi (P. placenta, C. versicolor or Schizophyllum commune) or as control blocks. The agar-block method (McNabb, 1958) with an exposure period of 10 weeks was used to determine rates of decay. Data were obtained from approximately 3,000 blocks which were analyzed statistically.

RESULTS

Growth and decay rates of black walnut are shown in Table 1. Tree 1 was a consistently fast growing tree, tree 4 a consistently slow growing tree and trees 2 and 3 were growing relatively fast when the heartwood tissue was formed but recent growth was only one-half that of earlier growth. Analysis of variance revealed significant differences in decay resistance between trees for a given fungus but these differences were not correlated with growth rate (Table 1).

Table 1.--Growth and decay rate of slow- and fast-growing black walnut collected in Michigan

Wood type and tree number		Average no. of annual rings/cm	Weight lost - % dry weight	
			Poria placenta	Coriolus versicolor
Heartwood	1	1.8	21.4	3.9
	2	3.0	11.6	5.8
	3	3.7	17.4	7.5
	4	6.5	16.1	3.7
Sapwood	1	2.0	29.3	10.5
	2	6.5	34.4	6.7
	3	7.0	31.1	12.7
	4	7.0	33.4	14.1

To answer the question 'Does the durability of the outer heartwood differ from that of inner heartwood?' an analysis of variance was run on the data for each state for each of the three fungi. Data for all three trees and for all three locations within the tree (top, middle, and bottom) were lumped for analysis. As expected, the sapwood was consistently more decay susceptible than the heartwood. However, outer, middle and inner heartwood did not differ significantly from one another in their rates of decay (fig. 2).

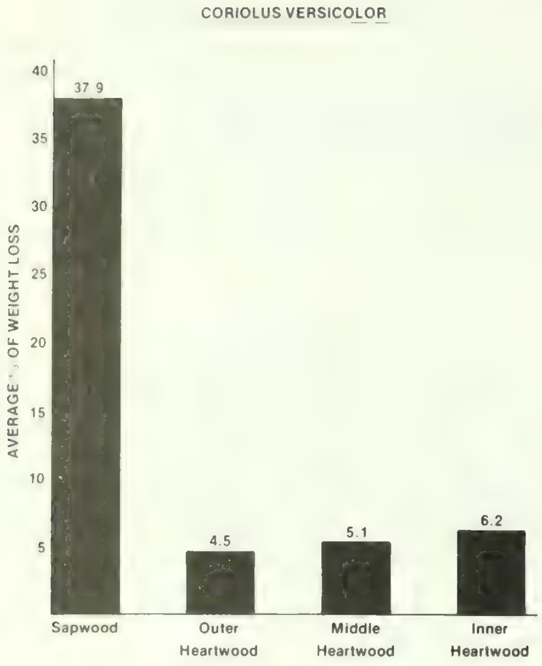

Figure 2.--Decay rates of black walnut sapwood and heartwood when exposed to Coriolus versicolor for 10 weeks. Decay rates for Poria placenta and Schizophyllum commune showed a similar pattern.

A similar procedure was used to determine if the sapwood or heartwood from the top, middle and bottom of the trees differed in their resistance to decay. Rates of decay for the sapwood did not differ significantly with position in the tree. Generally, the same pattern was true for the heartwood (fig. 3). However, P. placenta was capable of causing a faster rate of decay of bottom heartwood compared to heartwood from the top for trees collected from Pennsylvania and Kentucky (fig. 4).

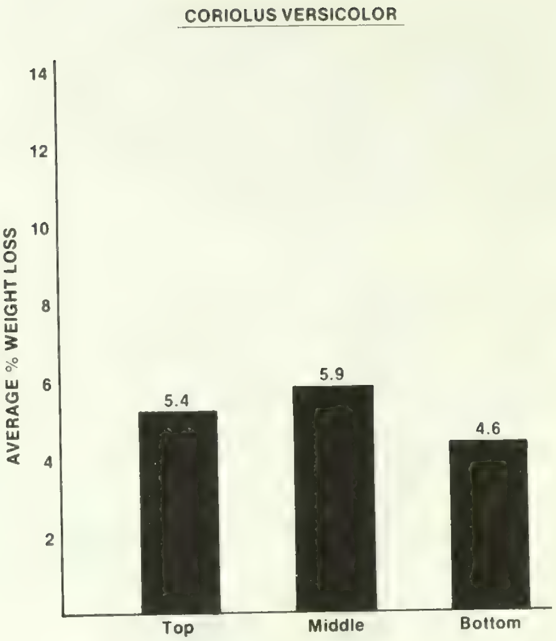

Figure 3.--Decay rates of black walnut heartwood collected from the top, middle and bottom of the trees when exposed to Coriolus versicolor for 10 weeks.

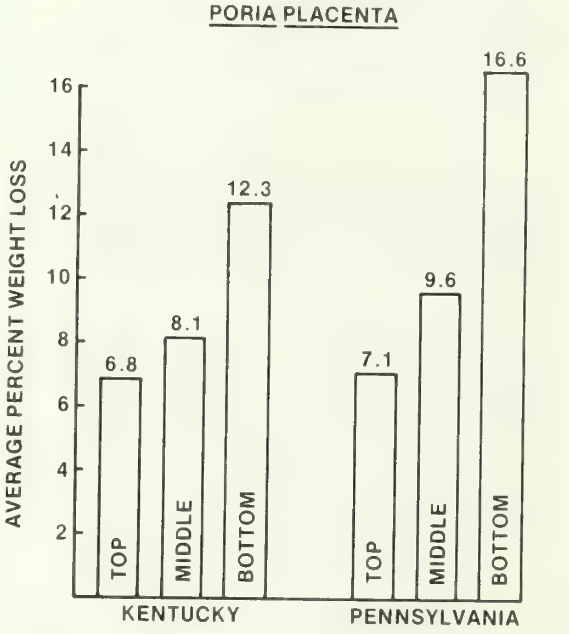

Figure 4.--Decay rates of black walnut heartwood collected from Kentucky and Pennsylvania when exposed to Poria placenta for 10 weeks.

The decay rates of the heartwood for each tree were compared for trees collected in each state to determine if durability varied between trees on the same site. Decay rates were not significantly different between trees for either C. versicolor or P. placenta for trees collected in Michigan, Kentucky or Pennsylvania. However, there were differences between trees collected in Kansas and Wisconsin. The heartwood from tree no. 2 from Kansas was significantly more decay resistant when exposed to either C. versicolor or P. placenta than either trees no. 1 or 3 (figs. 5-6).

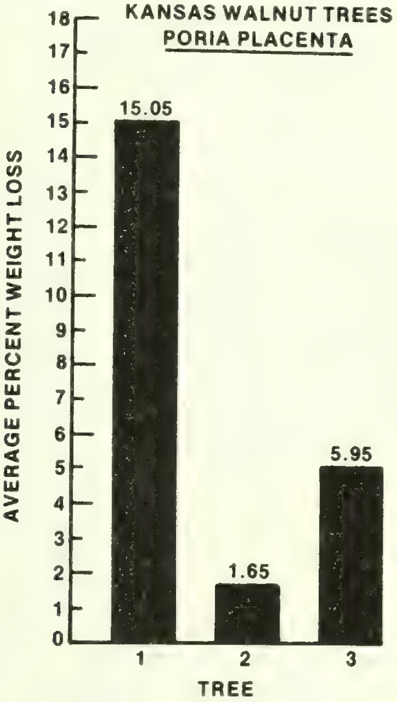

Figure 5.--Decay rates of black walnut heartwood collected from three trees in Kansas and exposed to Coriolus versicolor for 10 weeks.

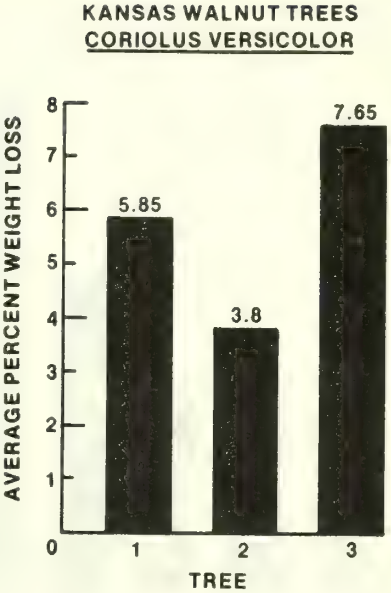

Figure 6.--Decay rates of black walnut heartwood collected from three trees in Kansas and exposed to Coriolus versicolor for 10 weeks.

The last comparison was between states, i.e. does the durability vary from one state to another. Rates of decay for heartwood from all radii, positions and trees were lumped for each state. An analysis of variance was then conducted to determine differences between states. Heartwood from trees collected in Kentucky and Pennsylvania decayed at a significantly faster rate than heartwood collected in Kansas, Wisconsin and Michigan when exposed to C. versicolor (fig. 7). However, there were no significant differences in decay rates between states when the heartwood was exposed to P. placenta (fig. 8).

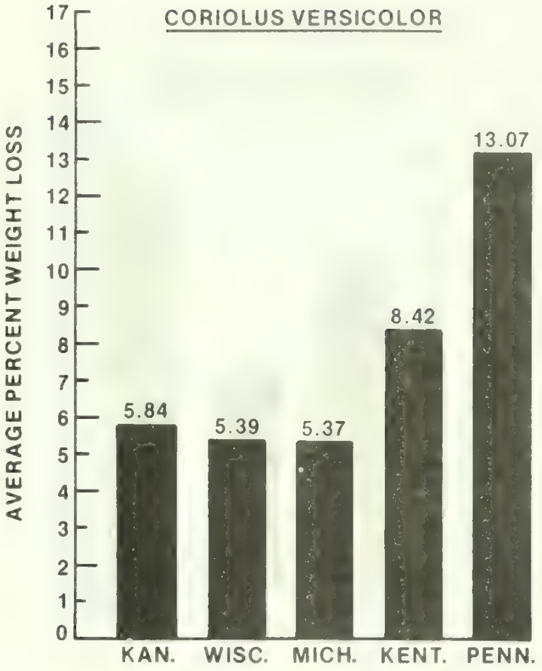

Figure 7.--Decay rates of black walnut heartwood collected from five states and exposed to Coriolus versicolor for 10 weeks.

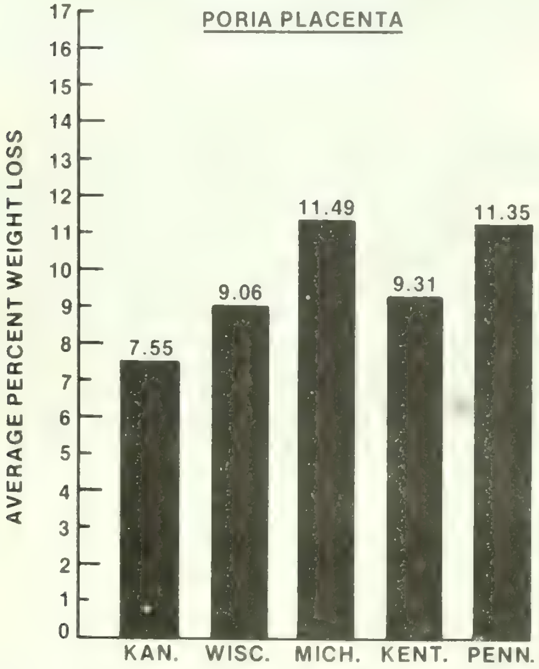

Figure 8.--Decay rates of black walnut heartwood collected from five states and exposed to Poria placenta for 10 weeks.

DISCUSSION

The heartwood from fast-growing plantation trees should be just as decay resistant as the heartwood from slower-growing trees in natural stands, according to evidence presented above. Since wood durability is directly correlated with the amount and type of heartwood extractives formed when sapwood is transferred into heartwood, it appears heartwood formation is basically the same in fast and slow-growing trees. This has additional significance because heartwood extractives give walnut its distinctive color and influence its workability.

The fact that the heartwood did not vary in decay resistance radially differs from previous reports (Scheffer and Cowling, 1966). Radial gradients in decay resistance are the result of chemical alteration (polymerizations) of the toxic components as the heartwood ages. This explains, at least in part, why we find hollow trees in nature.

My results with black walnut would suggest that the compounds responsible for decay resistance do not polymerize as the heartwood ages. However, not enough is known about the chemistry of decay resistance in walnut to provide a conclusive explanation of why there seems to be little chemical alteration as the heartwood ages. The explanation of this phenomenon of consistent decay resistance will have to await further investigation.

While variation in decay resistance of the heartwood within individual trees differed from previous studies, variation in decay resistance between individual trees and between trees from different sites was similar to previous reports (Scheffer and Cowling, 1966). It is known that individual trees of the same species may vary considerably in their decay resistance and that this variation is primarily genetically controlled. The data presented support these previous conclusions. If significant variations in decay resistance occur between trees from a given state (e.g. tree 2 from Kansas, figs. 5-6), the variation is most likely due to genetic differences and it should not be attributed to site differences. All trees from one state were collected from the same site. On the other hand, there were major site differences between states, yet decay resistance as measured by P. placenta did not differ significantly between states. Even though there were some differences in decay rates caused by C. versicolor, trees from Kansas, Wisconsin and Michigan were remarkably similar even though the sites of collection were not similar.

Additional collection of trees will be made during the coming year in Indiana, Illinois, Mississippi and North Carolina. Hopefully, this additional sampling will help clarify variations in decay resistance of black walnut throughout its range.

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EPIDEMIOLOGY OF BUTTERNUT CANKER[1]

N. A. Tisserat and J. E. Kuntz[2]

Spores of Sirococcus clavigignenti-juglandacearum, the causal fungus of butternut canker, were liberated only during rainfall by the action of rain splash impaction on the spore matrix of fruiting pycnidia. During rainfall, conidia were trapped on rotorod samplers up to 30 m from cankered trees, although observation of natural spread indicated some spores probably travel greater distances. A high concentration of spores were washed down the tree trunk from branch cankers in stem-flow water. Infection and canker development following artificial inoculation occurred throughout the summer on butternuts in the field. Natural infection of potted seedlings placed under diseased trees occurred from late July to October. The fungus continued to sporulate heavily on recently killed, cankered trees that remained standing or that were felled. These trees served as potential inoculum reservoirs.

INTRODUCTION

Butternut canker, first reported in Wisconsin in 1967 (Renlund, 1971), is the most serious disease of butternut (Juglans cinerea L.). Since the first report, the disease has been found throughout the natural range of butternut in eastern United States (Anderson and LaMadeline, 1977) and threatens to eliminate this beautiful and valuable hardwood in many areas of the country (Nicholls, 1979). The disease is especially severe in southern Wisconsin where some survey plots had a disease incidence of 80% (Prey and Kuntz, 1981). Symptoms of the disease include branch mortality and multiple cankering of both the main stem and the buttress roots. The causal organism has been identified as the imperfect fungus, Sirococcus clavigignenti-juglandacearum (Nair et al., 1979).

A better understanding of the epidemiology of butternut canker, especially with regards to environmental conditions favorable for sporulation, spore dispersal, and infection, is needed before silvicultural control measures can be recommended. The objectives of our research were 1) to identify environmental conditions favorable for sporulation and dispersal of the pathogen; 2) to examine the rate at which branch and stem cankers develop; and 3) to evaluate the potential of dead or dying butternuts to serve as inoculum sources.

Spore Liberation and Dispersal

Seasonal spore release was studied in pockets of diseased butternuts in the University of Wisconsin Arboretum, Madison, during 1979 and 1980. Vaseline-coated microscope slides were placed beneath cankered trees and removed at daily or weekly intervals. The number of spores per interval was determined by counting all S. clavigignenti-juglandacearum spores in 20 random light microscopic fields at X430. Spores of the fungus were liberated from cankered trees from mid-April through October in both years, but only during those days in which there was measurable rainfall. Table 1 indicates results for the 7-day period of June 15-21, 1979. Slides placed beneath trees directly after rainfall or during periods of relative humidity greater than 90% did not have spores deposited on them. Spore collection on rotorod and Hirst spore traps also showed that liberation of conidia only occurred during rainfall.

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Table 1 Number of spores trapped daily on vaseline-coated microscope slides placed beneath a cankered butternut tree.

	June 1979						
	15	16	17	18	19	20	21
Rainfall (inches)	0	0	.13	0	.60	.10	0
Number of spores[1/]	0	0	186	0	275	134	0

1/ Total spores on 20 fields at X430.

The spores of S. clavigignenti-juglandacearum are tightly bound in a gelatinous matrix as they are extruded from pycnidia embedded in stromatic tissue beneath loosening outer bark, and are not easily removed, even under windy conditions. Preliminary experiments with blowing air, mist, and water droplets proved that rain splash impaction on the matrix is needed for liberation of the spores (Tisserat et al., 1981).

Many of the spores liberated from branch and stem cankers during rainfall are washed down the tree trunk in stem flow water. The quantity of conidia in stem runoff was determined by placing water-tight funnel traps around the main trunk of two cankered trees (dbh 20 cm) at a height of 1 meter. After periods of rainfall, stem runoff collected in the funnels was siphoned into 1 liter plastic bottles. The runoff water then was centrifuged at 8,000 g for 20 minutes to sediment the S. clavigignenti-juglandacearum conidia and other particulates. The sediment was resuspended in a mixture (5:1 v:v) of distilled water and trypan blue in lacto-phenol (for easier identification of the spores). The concentration of S. clavigignenti-juglandacearum spores in the suspension was determined with a light-field haemacytometer, and the number of spores/ml water was adjusted to the original amount of stem runoff water in each sample. Concentrations greater than 100 spores/ml of runoff water were common and occasionally concentrations higher than 10,000 spores/ml were recorded (Table 2). Spores in rainwater flowing down the stem can become lodged in lenticels, bark cracks, and wounds where they may germinate and start new infections. This may explain the multiple cankering typical of diseased butternuts especially on the lower trunk and buttress roots. Cankers of various ages and sizes commonly occur on the same tree.

Table 2 Mean number of S. clavigignenti-juglandacearum spores/ml in stem-runoff water from two heavily cankered butternut trees for 3 rainfall dates in 1980.

	Number of spores/ml stem-runoff[1/]		
	6/27/80	7/4/80	7/16/80
Tree 1	5.2×10^2	2.3×10^2	2.5×10^2
Tree 2	1.3×10^4	2.2×10^4	1.5×10^3

1/ Mean of two samples, five counts per sample.

One of the unique symptoms of this disease is the formation of basal stem and buttress root cankers. Basal cankers may extend below the soil line to a depth of 30 cm, but appear to progress laterally for only a few cm on the roots before marginal callus forms. The girdling of the cambial regional at the base of the tree by multiple cankers is often the cause of tree death, rather than girdling occurring higher on the trunk.

Buttress roots also may become heavily cankered. Roots exposed at the soil line have been found to be cankered up to 2 m from the trunk, but cankers on roots below the soil line have not been detected. The possibility of tree-to-tree spread of the fungus through root grafts is being studied.

The spores of S. clavigignenti-juglandacearum also can be carried from tree to tree in rainsplash droplets resulting in new infections. Spore dispersal gradients from an isolated pocket of diseased butternuts were determined by placing rotorod spore traps at 7.5 m intervals to 30 m downwind from the trees. The number of spores impacted on the traps during rainfall was plotted against the distance the traps were placed from the inoculum source (Fig. 1). Spore numbers decreased rapidly as the distance increased from the inoculum source, but some conidia were trapped at 30 m. The curve is hollow shaped, similar to curves of many airborne fungal spore and pollen dispersal gradients.

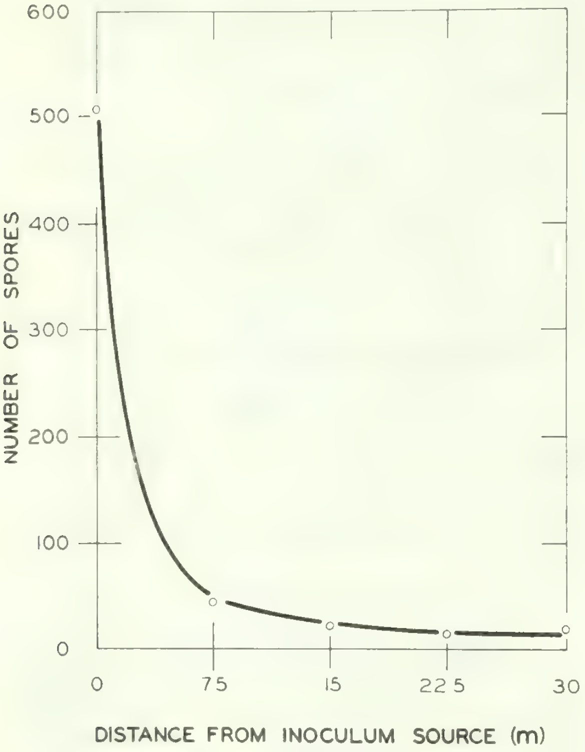

Figure 1. Average number of S. clavigignenti-juglandacearum spores caught during five rainfall periods (1980) on rotorod traps positioned up to 30 m from a diseased pocket of butternuts.

Spore dispersal curves may be useful in determining eradication distances needed to prevent the influx of inoculum into healthy butternut stands. Similar curves have been used to define the zone for Ribes eradication in white pine blister rust control programs (Van Arsdel, 1961). Based on our present results, we recommend that all diseased butternuts should be cut, removed, and destroyed for at least a 60 m radius from a healthy butternut stand or black walnut plantation. Butternuts and black walnuts should not be planted under or near diseased butternuts. While these control measures should reduce the amount of inoculum reaching healthy butternuts and black walnuts, they may not eliminate infection since it is not known whether insects or other vectors also aid in spore dissemination.

To determine environmental conditions favorable for infection, groups of 30 potted butternut seedlings were placed among cankered trees in the woods at two-week intervals (May through October, 1980). After each two-week period, the respective seedlings were brought back to the greenhouse and observed for symptoms of butternut canker. Most naturally invected seedlings showed initial symptoms witnin 2 weeks. Nevertheless, all seedlings were held in the greenhouse to observe canker development.

None of the seedlings placed in the woods prior to August 1 became diseased. Some seedlings placed out from August 1 through October became infected and subsequently were killed by the fungus. Leaf scars appeared to be the major infection court, but lesions also developed at lenticels and at the root collar on several trees. Initial symptoms appeared as small black necrotic flecks which rapidly expanded to dark brown ellipitical lesions. Bark cracking was commonly observed at the lesions, followed by an inky exudate from the opening. The root collar or basal stem lesions progressed into the root itself causing black irregular lesions on the main tap root of young seedlings.

Early in the summer, rainfall was sparse and the weather was hot and dry. In contrast, frequent heavy rainfalls occurred from mid-July through September. Natural infection of the potted seedlings occurred only during the late-summer rainy period. Rainfall and high relative humidity are optimal for spore dispersal and infection by S. clavigignenti-juglandacearum (Kuntz et al., 1979). The results also support the hypothesis that a major infection period is in the late summer and early fall. Fresh leaf scars during this time create a suitable infection court for the fungus (Kuntz et al., 1979).

Canker development

Canker development was studied in a plantation of butternuts at the University of Wisconsin Arlington Experimental Farm. Ten trees were inoculated bi-weekly from May 1 through October 10, 1980, by puncturing three leaf scars on a healthy branch with a dissecting needle and placing approximately .05 ml of a spore suspension (10^6 Sirococcus spores/ml water) on the wound. Cankers formed on branches after all inoculation dates. Two types of canker development were noted. In the first type, lesions appeared discrete, sunken, and were bounded by a callus layer. Cankers of this type progressed slowly and the branches were still alive after six months. In the second type, fungus invasion and colonization of the branch after inoculation occurred rapidly. Some branches were killed and hyphal pegs were produced in as little as one month after inoculation. No distinct canker margin was noted on these branches. The reason for the difference in reaction types is not known, but it was noted that those inoculated branches that died rapidly were partially shaded or were located on the lower portion of the tree. The shaded branches may have been physiologically stressed and were more susceptible to colonization by the fungus. In other cases, no cankers developed until the spring following inoculation in late summer.

Inoculum source

To determine whether felled trees could serve as important inoculum sources, five heavily cankered trees, 8-11 cm in diameter and 8-11 m tall, were cut and placed on the forest floor (February , 1980). By June 1, 1980, all cut trees showed evidence of extensive colonization and sporulation by S. clavigignenti-juglandacearum, even beyond the originial canker margins. Large quantities of spores were produced. Therefore, infected trees should be removed from the site to prevent inoculum buildup. Present studies seek to determine if basal stem girdling or poisoning of diseased trees will hasten bark shedding and tree drying and thereby reduce sporulation by the fungus.

CONCLUSION

Spores of the fungus Sirococcus clavigignenti-juglandacearum are liberated during rainfall by rain splash impaction. A high concentration of spores from cankered branches are washed down the tree trunk via stemflow water, leading to multiple infections of the same tree. The multiple cankers eventually girdle the cambium resulting in the death of the tree. The girdling often occurs at the base of the tree (at the soil line) rather than higher on the trunk.

Short distance dispersal of inoculum occurs when splash droplets containing spores are windblown from tree to tree. Spores have been trapped 30 m from a diseased pocket of butternuts during rainfall, although observations of natural spread among butternut plantings indicate spores travel even greater distances. Mechanisms of long distance dispersal of the fungus are not known but it has been postulated that vectors, spores traveling in aerosols, or both may be involved.

Infection and canker development after artificial inoculation can occur at any time during the summer. Twigs and small branches can be killed in as little as one month. In 1980, a major infection of noninoculated, potted seedlings placed under diseased trees occurred during rainy, humid conditions from August 1 through October. These dates corresponded with senescence and leaf drop. Fresh leaf scars are known to be infection courts of the fungus. From such late summer and fall infections, cankers appear and develop rapidly the following spring.

The fungus sporulates heavily on recently killed or cankered trees, either standing or felled, which serve as a potential inoculum reservior. In order to prevent inoculum buildup, dead or dying trees should be removed from the site. Walnuts and butternuts should not be planted under or near cankered trees.

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THE DISTRIBUTION AND IMPACT OF BUTTERNUT CANKER IN WISCONSIN[1]

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Widespread dying of butternut (Juglans cinerea L.) was reported in 1967 in southwestern Wisconsin. Since then, this canker-dieback disease, incited by the fungus Sirococcus clavigignenti-juglandacearum Nair et al, has been found throughout eastern U.S.A. Diagnostic symptoms have been described, the disease cycle clarified, and the host range expanded. Current studies concern disease epidemiology and possible disease resistance in butternut and other Juglans species.

INTRODUCTION

Widespread dying of butternut (Juglans cinerea L.) first was reported in southwestern Wisconsin in 1967 (Camp, 1967; Renlund, 1971). The number and extent of the diseased areas and the deterioration of the dead trees indicated that the disease had been active for several years (Kuntz et al., 1977). Canker-dieback since has been found throughout the range of butternut in eastern United States (Anderson, 1978; USDA, 1976; USDA, 1977a; USDA, 1977b) and the fungus pathogen has been isolated from diseased specimens collected in Indiana, Illinois, Iowa, Michigan, Missouri, Minnesota, Ohio, and Wisconsin.

An initial examination of diseased trees indicated that Melanconium oblongum Beck was associated with branch dieback and fruited abundantly on dead branches. However, distinct cankers also were present on both living branches and trunks. In contrast, Graves description in 1923 (Graves, 1923) of the Melanconis disease in Connecticut specifically stated that no well marked lesions or cankers were found with the Melanconis dieback. Moreover, recent inoculations of young butternut seedlings and saplings with M. oblongum failed to incite either branch or stem cankers. The fungus is considered a weak parasite that needs a stressed host to permit its development (Hepting, 1971). Melanconis dieback also was reported on black walnut, J. nigra L., and other Juglans species (Graves, 1923).

Diagnostic symptoms of butternut canker include discrete, elliptical cankers of both bark and wood of twigs, branches, stems, and even exposed buttress roots (Kuntz et al., 1977; Kuntz et al., 1979; Nicholls et al., 1979). Young cankers commonly originate at leaf scars, other natural openings such as lenticels, buds, bark wounds including insect wounds, natural bark cracks, and occasionally at points apparently free of any injury. Older cankers on trunks are large, open or partly covered by shredded bark, vertically oriented, and perennial. Cankers of different ages and sizes commonly occur on the same tree. Some stem cankers have persisted for several years as evidenced by the repeated layers of annual callus and by differential growth-ring counts. In many cases, their origin is unknown. However, adventitious buds, dead branches, and branch stubs are present in the centers of some cankers.

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Peeling the bark from branches and trunks may disclose dark brown to black inner bark and wood of undetected cankers. Older cankers often bear shredded bark underlain with blackened wood, may be bordered by repeated callus layers, and frequently coalesce to girdle branches and stems. Branch suckers and trunk sprouts often develop below the girdled portion, are readily infected, and die shortly thereafter. Sprouts are infected commonly in the fall through leaf scars and small, irregular lesions or large dark areas develop rapidly early the following spring. Infection of lenticels result in tiny, round, chocolate brown lesions of the bark. Initially only the outer bark is infected, but soon the wood is invaded (Jutte et al., 1978). On older trees, in the spring and early summer, an inky black exudate issues from canker fissures; later in summer, sooty black patches remain. Often the exudate also indicates initial infections and incipient cankers. Eventually, infected trees die.

It is now known (Jutte et al., 1978; Nair et al., 1978; Nair et al., 1979) that under the outer bark, the causal fungus forms a thin, black mycelial stroma from which arise hyphal pegs and pycnidia. Spores are extruded either in sticky masses or as fine, hairlike cirri. Spores are dispersed by rain or mist and disseminated by wind (Nicholls, 1979; Tisserat et al., 1981). The role of insects and other possible vectors remains unknown.

In 1969, studies were initiated on the etiology and epidemiology of butternut canker (Kuntz et al., 1979). The causal fungus, coded BN-5 and identified as a new *Sirococcus* species (Nair et al, 1978; Nair et al., 1979), was readily isolated in pure culture on common nutrient media from both bark and wood. The pathogen grew best at 24-28 C in light or dark; formed characteristic mycelial colonies, hyphal pegs, and pycnidia in culture; and sporulated profusely, especially when growing on thin malt agar. Inoculations of fresh wounds with mycelium, the spore matrix, or a spore suspension in water incited lesions on midribs and petioles of leaves and cankers on branches, stems, and roots of butternut and black walnut seedlings and saplings (Kuntz and Prey, 1978). Both hyphal pegs and sporulating pycnidia frequently formed on the thin fungus stroma beneath loosening outer bark of inoculated seedlings and saplings.

MATERIAL AND METHODS

Wisconsin's 1968 Timber Resource Survey (Spencer and Thorne, 1972) was used to locate forest inventory plots containing butternut. A maximum of five one-fifth-acre plots per county was selected and examined by U. S. Forest Service and WDNR field crews in 1976. Where possible, up to 50 butternut trees were examined on or adjacent to each plot. Data were recorded as to general tree health, canker incidence, limb or top dieback, and death from cankering or other causes. Trees also were grouped into poletimber (< 10 inches or 25 cm dbh) and sawtimber (> 10 inches or 25 cm dbh) classes. Dying or cankered branches were collected from diseased trees in each plot. Isolations for possible pathogens (Kuntz et al., 1977; Nicholls et al., 1979) were made in the laboratory on acidified potato dextrose agar (PDA) medium.

RESULTS

A total of 2,882 butternut trees were examined on or adjacent to 83 study plots in 33 counties. Of all trees examined, 44% appeared healthy, 30.9% were stem-cankered, 42.1% exhibited some degree of branch cankering and dieback, and 8.7% already were dead. Of all trees examined, 61.8% were classed as poles and 38.2% were sawtimber. Of the poles, 34.5% were cankered; of the sawtimber, 25.1% were cankered.

In several counties in northeastern Wisconsin, no cankered trees were discovered. In contrast, in southwestern Wisconsin counties, as many as 80% of the butternuts were cankered and 32% were dead. The fungus pathogen was isolated from most cankers collected in western and southwestern Wisconsin but not from trees in eastern Wisconsin. In addition, the fungus was isolated from cankered butternuts in Iowa, Michigan, Minnesota, and Wisconsin. Meanwhile, *M. oblongum* was found on many dead branches throughout the range of butternuts in Wisconsin.

Cankers were found on all woody parts of diseased butternuts. Cankers developed on trees growing on many different soils and sites, including dry, infertile ridgetops with shallow soils as well as in moist, fertile bottom lands with deep soil. Trees of all ages and sizes growing in mixed and relatively pure stands were diseased. Infected trees occurred either in local pockets or over fairly extensive areas. In these disease areas, occasional butternuts appeared canker-free and healthy. So far, small branch and stem cankers have been detected on a few black walnuts growing in mixed stands with severely infected butternuts. The fungus pathogen was isolated from cankered walnuts. Walnut isolates, wound-inoculated into butternut and walnut seedlings and saplings, incited typical perennial branch and stem cankers. Especially with black walnuts, many inoculated branches died without forming distinct cankers. The fungus has been reisolated repeatedly during a 6-year period from perennial cankers on walnut stems.

DISCUSSION

Butternut occurs throughout the northern two-thirds of eastern United States under a wide range of soils and climatic conditions (Schroeder, 1972). Although it grows best on rich, deep moist soil, butternuts grow faster than do walnuts on dry, rocky soil.

Although, butternut is a minor species in Wisconsin (18.3 million cu. ft. net volume of growing stock) (Spencer and Thorne, 1972), select butternut lumber is second only to walnut in economic value (Peterson, 1977). In 1967, 343,000 cu. ft. of butternut were harvested, compared to 292,000 cu. ft. of black walnut (Spencer and Thorne, 1972). In fact, Wisconsin ranks second in the amount of butternut found in the United States and is a major producer of butternut lumber, used primarily for furniture, cabinets, and other fine woodwork (Schroeder, 1972; Spencer and Thorne, 1972).

In the past, butternut has suffered from few diseases (Hepting, 1971; USDA, 1960) or insect pests (Schroeder, 1972). Now, however, it appears that the canker is potential threat to butternut throughout its natural range (Anderson, 1978). Meanwhile, little or no regeneration of butternut has occurred in disease areas. Both sprouts and seedling trees are infected and rapidly killed. Fortunately, an occasional butternut remains healthy even though growing in the midst of severely cankered trees (Orchard, 1981). Whether such trees are "disease escapes" or are resistant to attack by the fungus pathogen is unknown. Branch and stem cankers are detected infrequently on black walnuts in woodlands even though artificial inoculations have incited cankers on walnut seedlings and saplings. Most cankers develop slowly, forming marginal callus. However, infected branches frequently die without forming distinct cankers. Hopefully, most black walnuts will remain canker-free. Otherwise, the increasing number of walnut plantings in the Midwest would be in grave danger.

The formulation of effective control measures must await further information, but certain silvicultural controls already are indicated. Meanwhile, do not plant walnuts or butternuts under or near infected butternuts. Canker distribution and impact in Wisconsin has been determined, the causal fungus has been identified, and its means of spread have been clarified. Present research seeks to clarify conditions favoring infection and disease development (Kuntz *et al*., 1979).

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REACTIONS OF JUGLANS SPECIES TO BUTTERNUT CANKER AND IMPLICATIONS FOR DISEASE RESISTANCE[1]

L. P. Orchard, J. E. Kuntz, and K. J. Kessler, Jr.[2]

Butternut canker, caused by the fungus Sirococcus clavigignenti-juglandacearum Nair et al, is the most important disease of butternut (Juglans cinerea L.). Infected butternuts often have many cankers and severely cankered trees die. Several economically important species belong to the genus Juglans. In order to determine their relative resistance or susceptibility, saplings of several Juglans species and hybrids were wound-inoculated under field conditions at the U.S.F.S. Tree Improvement Center, Carbondale, Illinois. Cankers developed on all inoculated species and hybrids including trees of J. nigra, J. regia, J. sieboldiana, J. regia x nigra, and J. sieboldiana x cinerea. Nine months after inoculation the largest cankers had developed on J. regia which appeared to be highly susceptible to the canker fungus pathogen.

INTRODUCTION

Butternut canker, caused by the fungus Sirococcus clavigignenti-juglandacearum Nair et al. (1979), is the most important disease of butternut (Juglans cinerea L.). The disease was noticed first in Wisconsin in 1967 (Renlund, 1971). In 1978, Anderson and LaMadeleine (1978) reported its occurrence throughout the range of J. cinerea in the eastern United States.

On butternut, the fungus incites perennial cankers, of various sizes and ages, which can occur at all heights on the twigs, branches, and stems. In the spring, a thin black fluid exudes from cracks in the bark; it stains the bark brown. This is often the easiest way to detect young cankers. The wood beneath the exudate is stained dark brown to black in a vertically oriented, elliptical pattern. Young cankers on branches appear as dark, irregularly elongate, sunken areas frequently associated with a leaf scar, lenticel, or various wounds. Older cankers are perennial, fusiform, vertically oriented, and may be wholly or partially covered with shredded bark. The fungus produces a thin stroma in the bark from which hyphal pegs and spore-bearing pycnidia form under the loosening outer bark (Kuntz et al., 1979). Infected trees usually bear numerous cankers and often die as a result.

In some stands all the infected butternut trees have died, but in other stands one or several apparently healthy trees remain. These canker-free trees are found in infection pockets where inoculum is abundant, which suggests that they may be resistant to the pathogen.

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[1] Paper presented at the 1981 Joint Meeting of Walnut Council/Northern Nut Growers Association. Purdue University, West Lafayette, Indiana, Aug. 9-14, 1981

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In addition to butternut, several economically important species belong to the genus Juglans. These include black walnut (J nigra L.), Persian walnut (J. regia L.), and Japanese walnut (J. ailantifolia Carr.) (Smith, 1953).

In order to determine their relative resistance or susceptibility to butternut canker, trees of these species and some of their hybrids were wound-inoculated with S. clavigignenti-juglandacearum under field conditions at the U.S.D.A. U.S. Forest Service Tree Improvement Center, Carbondale, Illinois.

MATERIALS AND METHODS

In October, 1979, certain Juglans species and hybrids, 10-20 years old, (Table 1) were branch-inoculated with mycelium and spores of S. clavigignenti-juglandacearum. Inoculated branches were generally 1-3 cm in diameter.

Six tangential slanting knife wounds, approximately 1-2 cm long, were made through the bark and into the sapwood on each tree tested. Four wounds were used for inoculations, and two served as noninoculated controls. Usually, the inoculated wounds were made on one branch and the control wounds were made on another branch, but sometimes the control wounds were made distal to the inoculated wounds on the same branch. Immediately after wounding, a piece of mycelial colony of the pathogen growing on agar was inserted into each of the four wounds used for inoculation. For controls, a piece of sterile agar alone was inserted into each of the two control wounds. The wounds were wrapped with wet cotton and covered loosely with aluminum foil.

In the spring of 1980, the inoculations were observed for canker development, and on July 31, 1980, all the inoculations were examined, cankers were measured, and symptoms were described.

RESULTS

Cankers began to appear and the fungus pathogen was reisolated in the early spring. Both confirm our observation of similar fall infections and rapid canker development in the spring on trunk sprouts. By July 31, 1980, cankers had developed on all species and hybrids which had been inoculated in October 1979 (Table 1). The cankers were distinctive for each species of Juglans. No cankers developed at any of the noninoculated control wounds. J. ailantifolia is now the accepted name for Japanese walnut and is synonymous with J. sieboldiana and J. sieboldiana var. cordiformis (Brinkman, 1974; McDaniel, 1979). In order to preserve information, however, the taxonomic designations below follow those used at the Tree Improvement Center.

Characteristic symptoms and signs of butternut canker for each species were as follows:

Table 1. Canker development following branch inoculations of Juglans species and hybrids.

Species	Trees Inoculated	Cankers measured[1]	Mean canker length (cm)
J. nigra	15	46	16.5
J. regia	15	51	19.5
J. regia x nigra	15	58	18.0
J. sieboldiana	8	28	14.0
J. sieboldiana var. cordiformis	9	34	10.5
J. sieboldiana x cinerea	3	8	14.0
J. cordiformis x cinerea	5	18	15.5
J. cinerea x cordiformis	6	12	19.0

[1] Cankers were not measured on branches that had been killed.

J. nigra

Cankers were usually externally indistinct, but were detected as a discoloration of the inner bark. Cankers were elliptical; chocolate brown exudate and/or a dry black "soot" appeared on some canker faces; branches 1 cm in diameter or smaller were killed; and hyphal pegs were produced beneath loosening bark on these dead branches.

J. regia

Cankers were slightly sunken to flat,but with distinct margins, often appearing blue-gray in color, elliptical in shape, and extending for roughly equal distances up and down the branch from the inoculation point. The bark often was cracked in the tissue alongside the canker. A chocolate brown exudate and/or a patch of sootiness appeared on some canker faces. Branches 1 cm in diameter died, and characteristic hyphal pegs developed under loosening bark on these dead branches. Branches 3 cm in diameter were approximately 3/4 girdled.

J. regia x nigra

Cankers resembled those on J. regia. Cankers were sunken, distinct, blue-gray in color, with longitudinal bark cracking both adjacent to and within the canker. Hyphal pegs were present occasionally on living branches.

J. sieboldiana and J. sieboldiana var. cordiformis

Cankers varied from indistinct, slightly sunken cankers to distinct, discrete, sunken to flat cankers. The branches often were swollen in the canker region with bark cracking alongside the canker. Occasionally there was a trace of sootiness on the canker face. On one tree of J. sieboldiana var. cordiformis, the inoculated wounds completely sealed and were indistinguishable from the check wounds except that the inner bark of the inoculated wounds was discolored (as with all inoculations), whereas the inner bark of the noninoculated checks was not discolored. Branches up to 2 cm in diameter were killed, and hyphal pegs formed on the dead branches.

J. sieboldiana x cinerea and J. cordiformis x cinerea

Cankers were distinct, sunken, and slightly discolored. Small branches (2 cm) were killed and dead branches bore hyphal pegs. Cankers resembled those formed on J. sieboldiana.

J. cinerea x cordiformis

Cankers resembled those formed on J. cinerea. Cankers were smooth, slightly sunken, light blue to gray often with a sooty patch, with abundant hyphal pegs, and little callus production along the canker margin.

DISCUSSION

The collection of Juglans species at the Tree Improvement Center at Carbondale, Illinois provided trees to inoculate under field conditions within the known range of the pathogen. The potential threat of S. clavigignenti-juglandacearum to Juglans species is great. With the exception of one tree (J. sieboldiana var. cordiformis), cankers developed at every wound inoculation on every tree, or the branch was killed by girdling before a discrete canker formed. We realize that our technique, i.e. direct inoculation of a wound with mycelium and spores of the pathogen, may mask some mechanisms of disease resistance. Such factors as low sporulation, inability of the inoculum to spread, adverse environment, or barriers to penetration could dramatically affect the course of the disease in the field. Nevertheless, given the high value of the trees, a severe technique established their resistance or susceptibility to cankering once infected. Factors which can influence disease incidence and severity for these species must be the subject of future investigations.

THE IMPORTANCE OF S. CLAVIGIGNENTI-JUGLANDACEARUM TO THE MAJOR JUGLANS SPECIES

Black Walnut

Kuntz et al. (1979) reported that black walnut is infected only infrequently in natural woodlands, but that artificial inoculations in experimental nurseries produce progressive, killing stem cankers on black walnut seedlings and branch cankers on saplings. Following our inoculations, cankers developed on black walnut; also inoculated branches of black walnut were killed more often than were those of other species tested. Current studies seek to determine whether infected black walnut branches die more often and more quickly than do infected branches of other Juglans species. If infected walnut branches do die rapidly, a hypersensitive reaction may exist. Such quick killing of infected host tissue might restrict further development of the pathogen and account for the low frequency of cankered walnuts in natural forest stands. Meanwhile, new plantings of black walnuts should not be made under or near cankered butternuts.

Persian Walnut

J. regia appears to be highly susceptible to S.clavigignenti-juglandacearum. At the Tree Improvement Center the longest cankers developed on this species. Because of this, butternut canker may become a serious disease through much of the world where this commercially important species is grown.

Further study will continue examination of these and other inoculations. Meanwhile detection surveys of midwestern plantings are needed to assess the disease potential of butternut canker on J. regia.

Hopefully the disease may not prove serious in some regions, e.g. California, for climatic reasons. Nevertheless, infected material must not be transported to regions where the disease has not been reported. Infected butternuts in the vicinity of Persian walnut plantations in the eastern United States should be removed and destroyed. Named varieties of Persian walnut must be tested for disease reaction and possible resistance.

Japanese Walnut

Japanese walnut is not as important a species as Persian walnut or black walnut. The species appears to be susceptible to the canker fungus. Nevertheless, the cankers that developed on this species were generally smaller, and on one tree the wound sealed and canker development was restricted. Possibly this species may provide a type of resistance in breeding programs, not only for improved Japanese walnut but also for butternuts, black walnuts, and Persian walnuts.

Butternut

Butternut is highly susceptible to S. clavigignenti-juglandacearum in all stages of growth; it may become an endangered species (Anderson and LaMadeleine, 1978). Canker-free butternuts do occur in infection pockets and may be resistant. Orchard et al. (1981) and Orchard (1981) reported a possible form of resistance in young butternut seedlings in which cankers do not develop in certain infected seedlings.Reasons for survival of asymptomatic seedlings, though infected, are sought. Whether this reaction can be a significant source of resistance in breeding programs is not yet known. Butternut is an attractive and useful nut tree that is hardy in the northern United States and southern Canada, but butternut canker must be controlled if this species is to be exploited. The role of environmental conditions, especially stress factors that may favor or inhibit infection and disease development, and possible resistance of selected species and hybrids also must be clarified.

SUMMARY

J. nigra, J. regia, J. ailantifolia, J. cinerea, and several of their hybrids are susceptible to S. clavigignenti-juglandacearum. The fact that J. regia proved highly susceptible to canker development following direct inoculation warns that butternut canker may well have international significance. Further testing must determine the long-term course of the disease on these species, especially J. regia, the nature of the "hypersensitive" reaction in J. nigra, the possibililty for resistance in J. ailantifolia and J. cinerea, and the environment and site factors that influence disease spread, especially for regions where the susceptible Juglans species are economically important.

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DIEBACK, DECLINE, AND STEM CANKER OF BLACK WALNUT IN WISCONSIN[1]

J. E. Kuntz and A. J. Prey[2]

Abstract.--The survival, growth, and productivity of walnuts are limited by several deleterious agents including diseases, insects pests, and weeds. Although many walnut diseases cause little economic loss, several can be destructive under conditions favoring infection and disease development. Recently in Wisconsin (SW), Iowa (NE), and Minnesota (SE), a vertical, elongate, and sometimes girdling stem canker has severely damaged and even killed young walnuts in plantations. Two species of *Fusarium* have been isolated consistently from representative cankers. One *Fusarium* sp. has induced cankers on stem-inoculated walnut seedlings in greenhouse studies. Meanwhile, this stem canker has been complicated by branch cankers associated with a *Phomopsis* species and twig dieback associated with a *Phyllosticta* species. Current research seeks to clarify the significance and relative roles of these fungus pathogens.

INTRODUCTION

Black walnut (*Juglans nigra* L.) is an extremely valuable hardwood in eastern and central United States, prized for the flavor of its nuts (Zarger, 1969), for the beauty of its wood (Blyth, 1973; Clark, 1969), and for its aesthetic appearance as a shade tree (MacDaniels, 1979). In recent years, its culture and management have been studied extensively (Clark, 1973), facilitating the establishment of numerous plantations in Central States (Burke and Williams, 1969; Schlesinger and Funk, 1977). To meet the increasing demand for planting stock, forest nurseries have greatly expanded their seedling production (Brinkman, 1974).

Unfortunately, the survival, growth, and productivity of walnuts are limited by several deleterious agents and including diseases, insect pests, and weeds (Berry, 1973; Bey and Williams, 1976; Johnson, 1969; Miller, 1973; USDA, 1979; Weber, Anderson, and Hoffard, 1980). Numerous plant pathogens, mainly fungal, attack walnuts of all ages and incite different types of disease (USDA, 1960). Although most walnut diseases cause little economic loss, several can be destructive under conditions favoring infection and disease development.

STEM DISEASES

Stem diseases of walnut are of special concern since they lower the quality and quantity of lumber and veneer logs, reduce nut yields, and may even kill infected trees. According to Hepting (1971), perennial target canker, caused by the fungus *Nectria galligena* Bres., seriously damages walnuts in the southern Appalachian region. In Wisconsin, this canker has been of little consequence.

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In contrast, recently in Wisconsin, Iowa, and Minnesota, a vertical, elongate, and sometimes girdling stem canker has severely damaged and even killed young walnuts in plantations. (Kuntz, Orchard, and Tisserat, 1980). The sunken, elongate cankers are of various sizes from small bark cracks to long, vertical strips, sometimes extending from the root collar into the crown. Both bark and wood are affected. In old cankers, bark loosens and sloughs off. Infected bark is dark brown with distinct margins adjacent to healthy tissue. Underlying wood is brown to black. Trunk or basal sprouts frequently develop below girdling cankers.

Two species of Fusarium have been isolated repeatedly from representative cankers. Pathogenicity of one Fusarium isolate has been demonstrated by wound-inoculation of walnut seedlings in greenhouse studies. Young walnut seedlings that became infected developed dark, sunken, elongate, stem lesions. In cases where stems were girdled, the inoculated seedlings died.

In two Minnesota plantings, more than 50% of the trees are cankered. (MN DNR, 1980). Most cankers range in age from 2 to 6 years old. Cankers may encompass either lateral branch pruning scars or dead branch stubs. Fortunately, in the field, most perennial stem cankers have progressed slowly and some cankers are closing by the formation of marginal callus.

A Fusarium canker of walnuts has been reported in North Carolina, Indiana, Tennessee, and Missouri (Minnesota DNR, 1980). Whether this stem canker is the same as that reported by Kessler (1974) to occur on walnut plantations in Illinois, Indiana, Missouri, and Iowa remains to be clarified. Kessler found an apparent symbiosis between Fusaria and ambrosia beetles, Xylosandrus germanus, which provided wounds and infection courts. Berry (1973) also reported a basal canker disease in plantation walnuts where bark and cambium tissues were killed at the ground line. The resulting canker girdles the stem and the crown dies. The cause is unknown. Recently, several species of Fusarium are reported to cause cankers on black walnut in the Midwest (Weber, Anderson, and Hoffard, 1980).

A major canker of butternut, incited by the fungus pathogen, Sirococcus clavigignenti-juglandacearum (Nair, Kostichka, and Kuntz, 1979), has been detected infrequently on black walnuts growing in mixed stands with severely infected butternuts (Kuntz et al, 1979). Nevertheless, artificial inoculations of young walnut seedlings, older saplings, and branches of mature walnuts have incited typical elliptical to fusiform, dark, sunken cankers or a rapid dying of inoculated branches. Girdling stem cankers frequently killed inoculated walnut seedlings. Trunk inoculations of walnut saplings incited slowly progressing perennial cankers from which the fungus has been isolated repeatedly (presently up to 6 years).

Meanwhile, these stem and branch cankers, together with the crown dieback and tree decline, have been complicated by small, dark, sunken branch cankers associated with a Phomopsis species and a rapid wilt and dieback of succulent shoots associated with a Phyllosticta species (U.S.D.A., 1960). Moreover, Melanconium oblongum Beck frequently invaded dead and dying branches where it fruited abundantly.

Detection and appraisal surveys will continue to monitor canker-diebacks of walnuts and butternuts. Meanwhile, current research seeks to clarify the role, impact, and activities of pathogens associated with these diseases.

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DEVELOPMENTS IN DISEASE CONTROL OF WALNUT ANTHRACNOSE

Steven Cline[1]

Abstract.--Walnut anthracnose, caused by Gnomonia leptostyla, is the most serious foliar disease of black walnut. Fungicide treatments, nitrogen fertilization, and mechanisms of disease resistance have and are currently being examined for use in anthracnose control. Benomyl sprays can reduce anthracnose severity but are restricted for use only on non-nutbearing trees. Chemical analysis of nut meat tissue detected benomyl but at levels below the federal tolerane level required for registration. Bioassays of benomyl residues on leaves and nut hulls showed that only two timed applications per year are necessary, provided normal rainfall conditions exist. Disease severity may be reduced by nitrogen fertilization. Trees treated with N alone had less anthracnose than those receiving other combinations of macronutrients. Resistance to anthracnose has been observed in juvenile leaves and is currently being investigated.

The fungal disease, walnut anthracnose, is caused by Gnomonia leptostyla (imperfect stage, Marssonina juglandis) and has become the primary important leaf pathogen of the host in the central and eastern United States. Berry, in the 1960's, suggested that this disease reduced tree growth through premature defoliation and that it affected nut quality and quantity. Exactly how damaging this disease is to growth and nut production is yet to be quantitatively determined.

Studies concerning mycology (Matteoni and Neely), pathogenesis, and epidemiology (Black and Neely) were done in the 1970's. The information that was generated has paved the way to better understand the host-pathogen relationships and the avenues for disease control strategy.

Disease control at the present time is limited to preventive cultural practices and the use of protectant fungicides applied to the foliage. Epidemiological studies indicate that tree moisture is essential for infection. Pruning trees to increase the sun's penetration and air circulation will hasten evaporation and reduce disease incidence. The removal of infected leaf material (overwintering site) is also suggested to reduce the inoculum potential. Under forest conditions this practice is not practical but certainly pruning could be employed by the homeowner for shade trees. At the present time, anthracnose control in walnut plantations is achieved with the use of protectant fungicides. Alternatives to fungicide applications are currently being investigated. Nitrogen fertilization seems to reduce disease severity. While disease-resistant cultivars are not currently available to growers, studies are being conducted to understand the nature of resistance observed in juvenile leaves and the applicability to breeding for resistance.

FUNGICIDES

Of six commercial fungicides applied as foliar sprays, by researchers at the Illinois Natural History Survey, benomyl (Benlate 50 WP, DuPont) at the rate of 1 lb/100 gal was the most effective for anthracnose control. Sprays were applied twice, one on June 2 and then on July 1. This fungicide was statistically superior to Topsin M 70 W, Manzate 200 80 W, Polyram 80 W. Bravo 6 F, and Triflorine 6.5 EC, giving 97% control over defoliation.

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The timing of fungicide applications is important to good control. Epidemiological studies in Illinois showed that infection from ascospores occurred in late May while conidial infections were produced in early July. To determine how the timing of benomyl sprays is important to control, a study was conducted to examine the persistence of this compound on black walnut leaves and nut hulls in 1978 and 1979. Four testing sites were chosen in Illinois. Foliar sprays were applied at the rates of 1 lb (1X), 2 lbs (2X), and 4 lbs (4X)/100 gal between late May and early July to established trees. Fungicide bioassays were conducted on samples of leaf and nut hulls collected at various periods following treatment. A benomyl-sensitive fungus was used to detect persisting residues on these plant parts. Rainfall was monitored over the testing periods.

Our results determined benomyl to be fairly persistent as the compound inhibited germ tube development for approximately 6 weeks on the foliar surface, provided that precipitation did not exceed 10 cm/week. Higher rates of application (2X, 4X) did not persist significantly longer than the 1X rate, implying that these higher rates would not increase anthracnose control. When benomyl persistence was studied under conditions following simulated rainfall applications, benomyl residues were inhibitory to germ tube development of the test fungus in excess of 24 cm of rainfall. Our conclusions suggest that other factors besides rainfall cause its removal or degradation under field conditions.

On nut hulls, benomyl was persistent for 5-7 weeks at the 1X rate while 2X and 4X rates remained effective in excess of 7 weeks. The effect of rainfall on nut hull persistence could not be determined.

Based on our studies in Illinois, we recommend spray applications of benomyl fungicide to begin in mid- to late-May when ascospores are released. A rate of 1 lb/100 gal was demonstrated to be effective for control of walnut anthracnose. With moderate (normal) rainfall, a second spray is not generally required until early July when conidia are released. When rainfall does exceed 10 cm/week, an earlier second application may be necessary.

The systemic action of benomyl and the uncertainty of movement into floral parts and developing nut meats limits its registration for use on non-nutbearing trees. To establish the potential for registration, we conducted a study to determine the level of residue accumulation of benomyl in nut meats following its application for disease control. In 1979, trees at Carbondale, Illinois were soil-injected or foliar-sprayed with benomyl or trunk-infused with Lignasan BLP. Nuts collected in August and September were analyzed for the breakdown product MBC (carbendazim) by gas chromatography. Results indicate that very low levels of MBC were present in several samples tested, however, in all samples examined, the quantities detected were well below the federal tolerance level of 0.13 ppm. We, therefore, have recommended the registration of benomyl for use on nut-bearing trees.

FERTILIZATION

Preliminary field testing of nitrogen fertilizers on anthracnose severity (Neely, 1981) from 1973-1977 showed that a reduction in diseased leaflets from 46 to 61% occurred as evaluated in August and September, respectively. This was studied more intensely in 1978 and 1979 in order to verify these trends. Tests were designed to establish the effect of nutrient source, rate and timing of fertilizer application. Nitrogen (N) alone and other combinations of nitrogen, phosphorus (P), and potassium (K) were compared at a uniform soil surface application rate of 29 g N/m^2 (1X) (6 lbs/1000 sq ft) applied in April, June or October. Additional applications of ammonium nitrate were made at 1/2X and 2X rates. A foliar treatment of urea was also tested spraying trees to run-off with three applications in mid-May, early June, and late June at the 10 g/l rate.

Black walnut is observed to be more resistant to anthracnose and there is a delay in premature defoliation when nitrogen fertilizers are applied. The rates of application are correlated directly with foliage color and growth, and inversely correlated with disease severity (table 1). Disease control increased by 20, 31, and 52% with 1/2X, 1X, and 2X nitrogen treatments as compared to the untreated controls. Soil-applied ammonium sulfate, ammonium nitrate, and urea were equally good nitrogen sources. Early spring as well as mid-summer applications are both effective. The combination of potassium and/or phosphorus with nitrogen reduced the effectiveness of nitrogen applied alone. Foliar treatments with urea were not significantly more effective than no treatment.

At present, we recommend fertilizing trees with N-containing compounds (ammonium sulfate, ammonium nitrate or urea) applied at the rate of 250 lbs/acre to reduce disease severity and stimulate tree growth. Fertilizers may be applied any time during the year, however, best response can be expected when applications are made prior to bud break in the spring.

Table 1.--Effects of nutrients applied to black walnut trees in 1978 and 1979.

Treatment	Rate (g/m^2)	Disease severity[2]	Color rating[3]	Diameter growth (mm)
None		44.0	3.1	4.3
Urea (foliar)[1]		44.7	3.3	4.8
PK	29	41.5	3.3	4.5
NPK	29	36.8	3.6	6.1
NH_4NO_3	14.5	35.2	3.5	5.0
NK	29	34.3	3.9	6.7
NH_4NO_3	29	34.2	3.7	6.5
NP	29	33.7	3.8	5.4
NH_4NO_3	29	31.1	3.9	6.0
$(NH_4)_2SO_4$	29	30.8	3.7	5.8
Urea	29	28.8	3.7	6.3
NH_4NO_3	58	21.3	4.1	7.7

[1] Three foliar applications sprayed to runoff at 10 g/l.

[2] Percentage leaflets with one or more lesions.

[3] 1=yellow green; 3=average green; 5=dark green.

RESISTANCE

Currently, cultivars resistant to walnut anthracnose are not available to foresters. Early attempts by Berry (1964) to rate infected field-grown trees across 40 cultivars failed to show conclusive evidence for disease resistance. When optimum conditions for infection were present, trees that were previously thought to be less susceptible became as severely infected as other cultivars. Attempts by Black (1977) to select for resistance among species of Juglans showed that a large variation in resistance exists. In field studies by Neely (1981) correlations between height, diameter, and anthracnose ratings were not significant, however, faster growing trees tended to be more resistant.

Observations of artificially infected and naturally infected leaves suggest that juvenile leaves are more resistant to infection than older, more mature leaves. Pathogenesis testing by Matteoni (1977) determined that leaves of all ages exhibited some lesions but lesions on younger leaves are smaller and either have fewer or no acervuli. Research efforts investigating the effects of nitrogen fertilization, leaf age and growth as related to anthracnose susceptibility, are currently underway to determine the potential applicability of this type of resistance for controlling anthracnose.

Walnut anthracnose is not well known in terms of the economic loss in annual growth and nut production. Successive years of premature defoliation can weaken trees and reduce the energy reserves from efforts to refoliate. Stressed trees are more subject to damage due to insects, root-rotting and other pathogens. While we recommend sound cultural practices (good site selection, scheduled pruning and a balanced fertilization program) to reduce favorable conditions for anthracnose development, fungicides are sometimes the only alternative. From our studies, benomyl is the most effective chemical means for control when applied to the foliage at the rate of 1 lb/100 gal. Current IPM strategies require that we move from pesticides to other means of disease control. Additional research efforts into alternatives are needed before they become valid, environmentally and economically sound.

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WALNUT ROOT ROT IN SEEDBEDS, HEELING-IN BEDS, AND STORAGE[1]

N. A. Tisserat, J. E. Kuntz, R. P. Guries, and R. F. Camp[2]

Root rot can be a limiting factor in the production of one-year-old (1-0) black walnut seedlings at the Wilson State Nursery, Boscobel, Wisconsin. So far, root rot in seedbeds, though present, has not caused serious damage; however, fall-lifted seedlings held over winter in heeling-in beds are subject to heavy losses resulting from root rot. Soil-borne fungi commonly associated with walnut root rot in Wisconsin included Phytophthora citricola, Cylindrocladium sp., and Fusarium spp. In most years, root rot of stored seedlings was avoided by spring lifting. Fall-lifted seedlings stored at 4 C in heavy paper bags had a much lower incidence of root rot and higher field survival rates than did fall-lifted, heeled-in seedlings. Survival rates of trees stored over winter in bags were similar to survival rates of trees that were spring-lifted.

INTRODUCTION

In recent years, the demand for quality black walnut (Juglans nigra L.) has increased walnut plantings throughout southern Wisconsin and adjacent areas of central United States. Intensive management is practiced to provide optimal growth and quality of the trees (Schlesinger and Funk, 1977). To insure proper density and uniformity, new plantations are established with one-year-old nursery transplants rather than by direct seeding. In Wisconsin alone, the state forest nurseries distribute annually over 300,000 black walnut seedlings. Spring planting of young seedlings is recommended since fall-planted stock is subject to winter injury and frost heaving (Schlesinger and Funk, 1977).

In Wisconsin until 1978, seedlings were machine-lifted in November, hand-graded, bundled, and placed in "heel-in" beds for overwinter storage in preparation for spring shipment. Frequently, in the heel-in beds, many of the injured roots deteriorated or rotted, resulting in extensive spring culling (Tisserat et al., 1980). Although the exact cause of root rot in Wisconsin is not known, soil-borne root-rotting fungi have been associated with some of the decayed roots. Studies in other areas of the country indicate that both environmental (Young, 1943) and biotic agents (Green and Ploetz, 1979) may be involved. Species of Cylindrocladium and Phytophthora have incited root rot of black walnut seedlings growing in nursery beds (Cordell and Matuszewski, 1974; Green and Pratt, 1970; Tisserat et al., 1980) and incipient infections by these fungi may contribute to subsequent root rot in the heel-in beds (Green and Ploetz, 1979). Root-infected walnut transplants seldom survive outplanting to the field.

Heavy losses of young walnuts due to root deterioration in the heel-in beds have led managers to consider other methods of storing seedlings. The purpose of our study was to evaluate several methods of overwinter storage and to identify some of the factors (both biotic and environmental) contributing to this problem.

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[1] Paper presented at the 1981 Joint Meeting of Walnut Council/Northern Nut Growers Association. Purdue University, West Lafayette, Indiana, Aug. 9-14, 1981.

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MATERIALS AND METHODS

Studies have been conducted from 1978 through May, 1981, and are continuing. One-year-old black walnut seedlings raised at the Wilson State Forest Nursery, Boscobel, Wisconsin were used in all studies. Seedlings were undercut approximately 20 cm below the soil surface the first week in November of each year. Undercut seedlings were hand-lifted, graded, and bundled into groups of 20 or 25 trees. Those trees which had a tap root of less than 20 cm in length or a root system showing discoloration were culled prior to bundling. Spring-lifted (April) seedlings were handled similarly.

Fall-lifted trees were stored overwinter either in heel-in beds or in heavy paper shipping bags. The heel-in method consisted of placing the bundled seedlings in trenches 30-45 cm deep dug in the seedbed. The roots then were covered with soil. Trees were overwintered in this manner until they were lifted in the spring. Other fall-lifted, bundled trees were placed in large shipping bags which were sewn or stapled shut. The bags were stored overwinter in large walk-in coolers maintained at a constant 4 C. No packing was added to the bagged seedlings, except in one treatment where damp straw mulch was distributed among the bundles of seedlings.

Fall-lifted seedlings were dipped in fungicides prior to overwinter storage. Bundled seedlings were immersed in one of several experimental fungicides for approximately one minute in the 1978-79 experiments (Tisserat et al., 1980). Two chemicals were tested further, in the 1979-80 and 1980-81 trials. The two fungicides were benomyl (Benlate 50% WP) at 5 lb active ingredient (a.i.)/100 gal water (6 g/l) and captafol (Difolatan 4F) at 4 lb a.i./100 gal water (5 g/l). Seedlings not treated, seedlings dipped in water only, and spring-lifted seedlings served as controls. A randomized complete block design was used.

In all experiments, data were recorded on the incidence of root rot before outplanting and seedling survival after outplanting. Any seedling showing root lesions and/or discoloration greater than one inch from the tip of the main tap root was considered rotted. Healthy seedlings showed little or no discoloration at the tip of the cut root, and were very firm in texture. The cortex of healthy roots was pearl-white in color. Discolored roots appeared spongy and water-soaked. The color of the rotted roots ranged from light brown to black. In other cases, rotted roots showed sunken, irregular, black lesions on the tap root. Tissue samples were taken from selected discolored roots, surface-sterilized in a 10% sodium hypochlorite solution for 2 minutes, and plated on potato dextrose agar. Typical discolored samples also were placed directly on VYS-PBNC, a selective medium for Phytophthora species (Schmitthenner, 1973). Pathogenicity tests of the isolates were made on one-year-old walnut seedlings planted in 12-cm diameter clay pots in a 2:1:1 (soil:sand:peat) mixture. Before planting the seedlings, a small agar block containing mycelia of the selected fungal isolate was placed in a knife wound made on the tap root. The seedlings were grown in the greenhouse for one month, then examined for root rot symptoms. Attempts were made to reisolate the causal organism from the rotted roots.

In 1979, all seedlings were outplanted by hand at the Knap Creek Wildlife Area near Boscobel, WI. In 1980, seedlings were outplanted at the Wilson State Forest Nursery. Transplant survival was recorded in September of the planting year. Since initial root rot and field survival were calculated as percentages of original seedlings, the data were transformed by the arc sin method (Snedecor and Cochran, 1967) prior to analysis.

RESULTS

Spring-lifting

In earlier studies the incidence and severity of root rot were compared between fall-lifted seedlings overwintered in heel-in beds and undisturbed seedlings left overwinter in the seedbeds. In some years, up to 100 percent loss occurred in the heel-in beds whereas little, if any, root rot was found in spring-lifted seedlings. Therefore, since 1978, overwintering root rot largely has been avoided by waiting until spring to lift the seedlings just before shipment.

Unfortunately, seedlings left in the seedbed during the winter 1980-81, and spring-lifted in April, also suffered extensive root deterioration. Surveys of the seedbed showed that 60% of the seedlings had complete root mortality and many of the remaining trees had varying degrees of root discoloration. Because the loss was so high and identifying healthy trees was so uncertain, the entire stock of black walnut seedlings was condemned.

Nevertheless, it appears that in most years, seedlings may remain overwinter in the seedbed, and may be spring-lifted without heavy losses from root rot. However this method may be disastrous in some years, as evidenced by the 1980-81 losses.

STORAGE METHODS

At the time the experiments were conducted, there was some question as to whether walnut seedlings would survive winter storage in the shipping bags. Results for all years show that fall-lifted seedlings survived overwinter storage at 4 C in sealed bags in excellent condition. In the 1979 plantings, little difference in root rot incidence and survival was found between the fall-lifted and bagged seedlings or seedlings overwintered in heel-in beds (Table 1). Seedling survival for all heel-in treatments averaged 93% compared to 95% for the bagged storage methods for that particular year. In contrast, data from the 1980 plantings indicated that the bagged seedlings had a lower percentage of root rot and a higher survival rate than did seedlings from the heel-in treatments.

Results from the 1980-81 experiments showed much larger differences between storage methods (Table 2). Fall-lifted seedlings placed in heel-in beds to overwinter without mulch had the highest percentage (75%) of root rot. Addition of straw mulch (marsh hay to 60 cm depth) to the heel-in beds resulted in reduced root rot. Seedlings stored in bags at 4 C had little or no root rot.

Table 1. Incidence of root rot in walnut seedlings following winter storage and survival after outplanting (1979-1980)

	Storage method			
	Bagged		Heel-in	
	1979	1980	1979	1980
Root rot[1]	4.8	1.0	5.8	23.8
Survival	95.0	87.7	93.0	70.0

[1] Values are percent averages of 15 replicates, 25 seedlings per replicate, 1979, and 30 replicates, 20 seedlings per replicate, 1980.

Root rot incidence and subsequent survival of bagged seedlings were unaffected by fungicide treatments (Tables 2 and 3). Seedlings with and without a water dip survived as well as did seedlings with a fungicide dip. However, a sparse, but unsightly, covering of fungus mycelia occasionally developed on bagged seedlings. Nevertheless roots were sound and the superficial mycelia did not affect seedling survival after outplanting. Both the benomyl and captafol fungicide dips reduced this molding of seedlings stored in the bags, and may be desirable as a prestorage treatment.

Table 2 Incidence of root rot (%) of black walnut seedlings following various overwinter storage methods and treatments, 1980-81.

Bagged					Heel-in (fall)	
No dip	H_2O dip	Benomyl dip	Captafol dip	Straw packing	Straw mulch	No mulch
2.0a[1]	0.0a	0.0a	1.0a	2.0a	7.0a	75.0b

[1] Mean percent root rot for 5 replicates, 20 seedlings per replicate. Values not followed by the same letter differ significantly (p less than .05) according to FLSD test.

Table 3. Effect of chemical and cultural treatments on storage root rot (winter 1979-80)and outplanting survival of walnut seedlings.

	No dip		H_2O dip		Straw		Benomyl		Captafol	
	Bag	Hi[1]	Bag	Hi	Bag	Hi	Bag	Hi	Bag	Hi
Root rot(%)	1a[2]	24d	0a	29e	0a	9b	0a	38f	1a	19c
Survival(%)	84b	68cd	85b	77c	94a	75c	92a	65d	83b	67d

[1] Fall-lifted heel-in treatments.

[2] Values represent an average of six replicates. Values in each row not followed by the same letter differ significantly (p is less than .05) according to FLSD test.

Associated Fungi

The role of fungi in the "overwinter root rot" problem is unclear. Several fungi were isolated from rotted roots stored in heel-in beds during the winters of 1978-79 and 1979-80. The most common fungi found were species of *Fusarium*, *Trichoderma*, and *Aspergillus*. Most of these fungi are not considered to be primary pathogens but can cause damage to weakened or injured root systems. Primary pathogens such as *Cylindrocladium* sp. and *Phytophthora citricola* were isolated less frequently from decayed roots. In both these years, very little root rot developed overwinter.

Root rot during the 1980-81 winter was severe, resulting in the loss of the entire crop. Attempts to isolate pathogens from discolored roots during April, 1981, showed that such roots were essentially sterile. Only rarely were fungi or bacteria found in rotted tissue. Because no biotic agent was isolated consistently, and the fact that fall-lifted seedlings in heavily mulched heel-in beds or stored in bags had very little root rot (Table 2) make it doubtful that fungi were the primary causal agents of root rot for that year.

Our results suggest that freezing temperatures or extreme fluctuations in temperatures in the heel-in beds or even in seedbeds may be important factors in the incidence of root rot. Initial studies indicated that bare-rooted seedlings exposed to freezing temperatures (-12 C for 30 minutes) prior to storage were heavily colonized by *Fusarium* spp. and did not survive outplanting the following year (Tisserat *et al.*, 1980). The incidence of root rot in the heel-in beds for the 1979-80 study (Table 1) was higher than that for the 1978-79 experiments. Seedbeds during 1978-79 had two to three feet of snow cover most of the winter while in 1979-80, the seedbeds had little or no snowcover the entire winter. Temperature extremes in the soil during 1979-80 and fluctuating soil temperatures during the winter of 1980-81 may have injured roots and predisposed them to attack by soil-borne microorganisms. In contrast, bagged seedlings stored at 4 C (Table 1) in both years had very little root rot.

CONCLUSIONS

In past years, overwinter storage of black walnut seedlings in heel-in beds resulted in extensive root rot. Our results suggest alternative methods for storage of black walnut seedlings during the winter months. Spring-lifting and immediate distribution of seedlings are preferable to the fall-lifting and heel-in method of storage in avoiding overwinter root rot. However, there is still occasional risk involved in spring-lifting, depending on winter conditions. Spring-lifting should be used only where cold storage facilities are not available. Moreover, fall-lifting and cold storage may be more convenient for nursery managers, enabling them to avoid the spring rush in lifting other tree species.

Therefore, we believe that the best method of storage in Wisconsin is fall-lifting, placement of seedlings in sealed shipping bags, and overwinter storage at 4 C. Care must be taken to keep the temperature at a constant 4 C, because freezing temperatures result in direct damage to roots, a high incidence of root rot, and poor field survival.

Fungicide dip treatments of seedlings prior to storage in bags at 4 C had little effect on root rot or field survival. No dip or water dip controls also were essentially free of root rot. However, the benomyl and captafol dips did reduce superficial molding of walnut seedlings stored in shipping bags. While the molding did not affect survival of outplanted seedlings, it was unsightly and could reduce the marketability of bagged seedlings.

While methods for avoiding the root rot problem during winter storage are now available, the exact nature of the root deterioration is still unclear. It does appear that cold temperatures or extreme temperature fluctuations contribute to the incidence and development of storage root rot either directly or indirectly. Whether other factors such as incipient infections by pathogenic fungi are involved is not known. Future research will attempt to clarify the relative roles of abiotic (environmental) and biotic agents.

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BLACK WALNUT CURCULIO:
A FACTOR IN WALNUT NUT PRODUCTION[1]

Larry M. Blair[2]

Abstract.--The black walnut curculio is discussed as an important factor in premature nut loss of black walnut. In Missouri trapping studies, nut drop resulting from curculio activity reduced potential harvestable yields by 19% to 78% in three geographic areas of the state. Average loss was 51%. A brief biology of the insect is presented.

Since World War II, new uses for nut shells and kernels of black walnut (Juglans nigra L.) have created a growing demand for black walnut nuts. Potential nut returns are an important addition to the value of the species. Management practices are being designed to improve growth conditions for nut production as well as lumber. Revenues from nut sales can be used to ease long-term carrying costs associated with lengthy stand rotations.

A major factor influencing demand for nuts in recent years has been the shortage of black walnut planting stock. Landowner awareness of walnut values has caused a significant increase in the number of plantations established. Most states have been unable to produce enough seedlings to meet these demands because of nut scarcity (Grey, 1971). The problem is complicated by competition from the nut industry. Aside from the importance of black walnut kernels as a food item, research has shown important uses for the crushed shells. Uses include filtering agents in smoke-stack scrubbers, additives to drilling mud in oil-well drilling, and polishing agents for chrome and automotive parts, among others (Cavender, 1973). In addition, Hammons Products Company in Stockton, Missouri, has recently been successful in boosting nutritive values of cattle feed by adding low grade walnut kernels to a corn feed mixture. Continued research promises additional uses for black walnut nuts in the future.

The black walnut curculio, Conotrachelus retentus (Say), is an important insect pest of walnut nut crops (fig. 1). The adult feeds on new walnut shoots and leaves, and the larva destroys developing nuts.

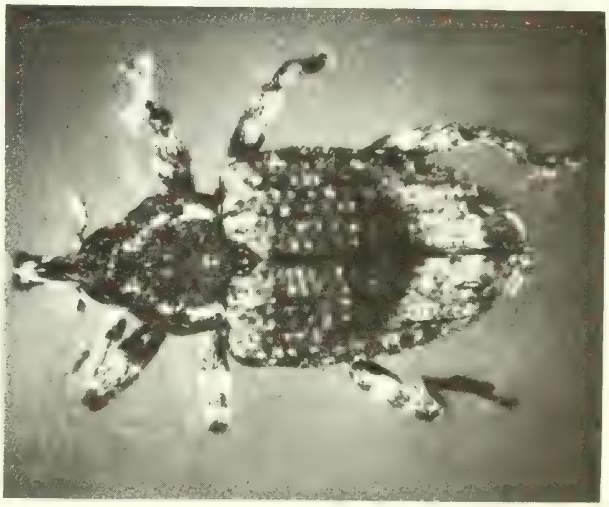

Figure 1.--Adult walnut curculio.

Previous research on this insect was limited, and revealed little about its habits and life history. Therefore, a research project was undertaken to study the curculio's biology and impact on walnut nut production in Missouri (Blair, 1978).

LIFE HISTORY

Adult curculios spend the winter in soil or heavy leaf litter near the base of walnut trees. Spring emergence is closely timed with bud break, and occurs from mid to late April. Newly emerged adults enter trees by crawling or flying. They feed on succulent foliage and male flowers with feeding damage appearing as a darkened spot on the base of the leaf stalk. It seldom causes leaf death, and is difficult to detect. Other feeding damage may occasionally appear as holes chewed in leaflets. However, this damage is similar to that of other leaf-feeding beetles, and is not diagnostic.

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[1] Paper presented at the Black Walnut Symposium, West LaFayette, Indiana, August 10-14, 1981.

[2] Larry M. Blair, Area Extension Forester, K.S.U. Area Extension Office, South Hutchinson, Kansas.

Eggs are laid on developing nuts shortly after the female flowers are fertilized. When nuts are small, single eggs are placed in crescent-shaped punctures chewed from the nut wall (fig. 2).

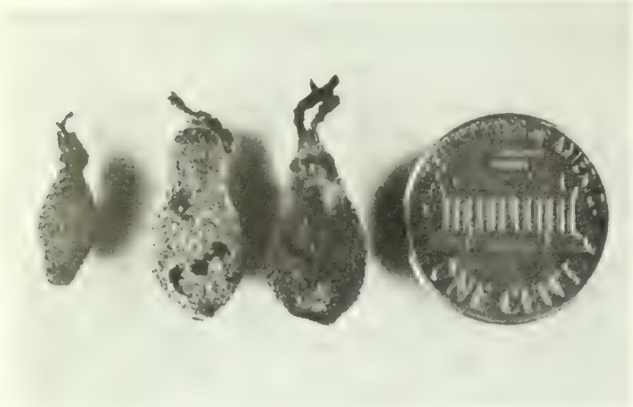

Figure 2.--Oviposition mark on nut.

Several eggs may hatch on a small nut, but the most active larva consumes the others to defend its food supply. On larger, more mature nuts, single eggs are placed in punctures resembling pin holes. These punctures are usually placed on the nut in clusters of 3 to 10. Large nuts may support the development of several larvae.

Hatching usually occurs five days after eggs are laid. Larvae bore into the watery centers of developing nuts and feed extensively. "June nut drop" occurs when infested nuts drop from trees in late May, June and early July. From the time the eggs are laid, it takes about three weeks for nut drop to occur. Most infested nuts abort when approximately ½" in diameter. For this reason, the premature nut drop is easily overlooked.

Larvae remain inside hollowed-out nuts for an additional two weeks before entering the soil to pupate. Nut exit holes are ¼" in diameter, and serve as evidence of curculio activity. The pupal stage requires three weeks and occurs at an average soil depth of two inches. After this, adult curculios emerge and feed on black walnut foliage until leaf drop occurs. Only one generation is produced per year.

SHOOT PROBLEMS

Infrequently, eggs may be laid on developing shoots of black walnut. Stem mining and loss of terminal buds are potential growth-form problems on young trees. However, surveys of Missouri walnut plantations under ten years of age revealed no curculio activity. Adult curculios probably do not associate with trees too young to bear nut crops.

IMPACT ON NUT CROPS

Missouri nut productivity studies were conducted in one area in 1976, and three areas in 1977. The initial study involved testing and comparison of three trapping designs at the Dupont black walnut plantation near Ashburn, Missouri. Trees in the plantation were 27 years old at the time of the study. Thirty-six trees were selected and sampled with 216 cone-shaped plastic traps. Traps were three feet in diameter, and each was suspended between two 5-foot stakes. Trap placement was statistically designed to accurately estimate damage for the entire plantation from sample tree collections.

Traps were checked weekly from early June until August, and biweekly for the remainder of the season. The collected nuts were dissected to determine the reason for early drop. Records were kept for each nut. Four factors were determined to influence premature abortion and loss to nut crops. These included curculio damage, infertility, squirrel activity, and natural abortion in response to moisture stress. Curculio damage had the greatest impact of the four factors. It accounted for 88% of the premature drop recorded during the two years of productivity studies.

Seasonal nut drop at the Dupont plantation in 1976 occurred in two distinct periods (fig.3). The "June nut drop" included all nuts which dropped before August 17 as a result of the four previously mentioned factors. These nuts were lost to production. The mature nut drop occurred from September 15 to November 5. Nuts which dropped during this period were harvestable. The black walnut curculio reduced the nut crop by 43% at Dupont in 1976.

The 1977 black walnut productivity study was expanded to include trapping sites in three geographic areas of the state. The Dupont plantation was again used to represent the northeastern part of Missouri. An unmanaged tract of black walnut near Fayette, Missouri, was used as a central Missouri site. The third site was an intensively managed black walnut fertilization plot in southwestern Missouri, near Stockton. Sample trees were of nut-bearing age, and ranged from 10" to 12" DBH. Thirty trees were randomly selected in each area. Each tree was sampled with four traps.

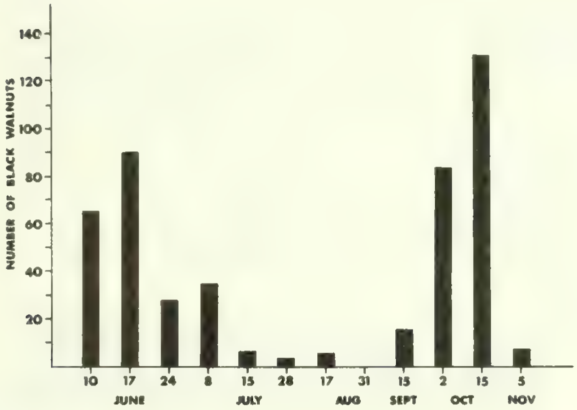

Figure 3.--Seasonal distribution of black walnut nut drop at the Dupont plantation, Ashburn, Missouri, in 1976.

Seasonal nut drop at the Dupont plantation differed greatly in 1977 from that of the previous season (fig. 4). Only a small percentage of the nuts reached maturity. Curculio damage was responsible for a 78% reduction of the potential harvestable yield.

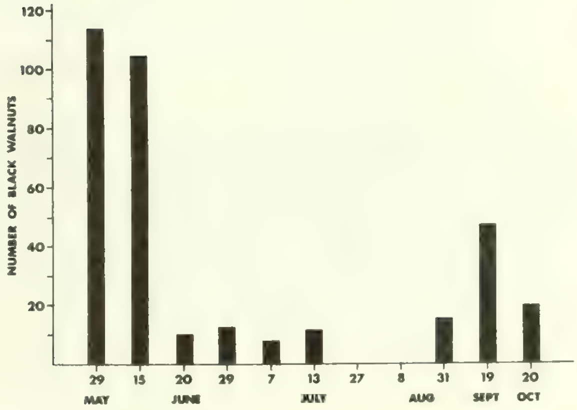

Figure 4.--Seasonal distribution of black walnut nut drop at the Dupont plantation, Ashburn, Missouri, in 1977.

A similar level of damage was recorded at the Fayette trapping site (fig. 5). Again, more nuts were collected during the June nut drop than during the mature drop. Sixty-six percent of the crop was destroyed by curculio activity.

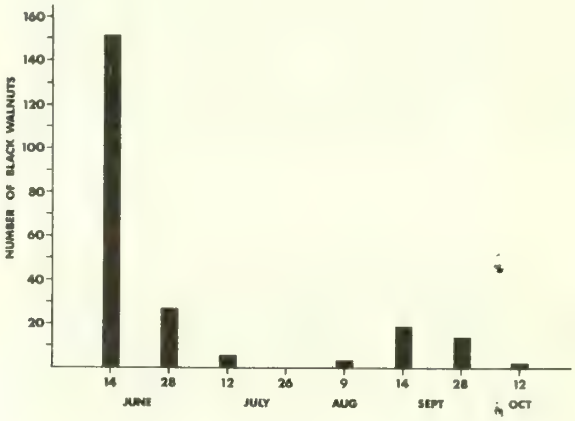

Figure 5.--Seasonal distribution of black walnut nut drop in natural forest, near Fayette, Missouri, in 1977.

The Stockton area was least affected by premature nut drop (fig. 6). Most of the crop reached maturity at this site. Curculio activity destroyed only 19% of the developing nuts.

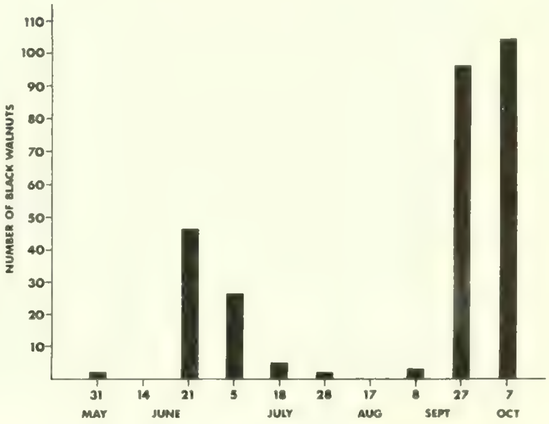

Figure 6.--Seasonal distribution of black walnut nut drop at the Fox plantation, Stockton, Missouri, in 1977.

This level of damage was not consistent with other Missouri areas. The comparatively low impact was possibly linked with site disturbance effected by former practices in the stand. Activities which affected the site included annual applications of simazine and paraquat to remove grass under trees, bulldozer work to release single trees, and the use of heavy equipment in an intensive spray schedule involving foliar fertilization. It is believed that the combination of compacted soil and lack of normal ground cover may have adversely influenced curculio populations on the site. This might explain the reduced level of curculio damage.

CONCLUSIONS

Seasonal nut collections in 1976 and 1977 showed that the black walnut curculio had an important impact on black walnut nut production in Missouri. Statewide, an average of 51% of the nuts collected in productivity studies dropped prematurely as a result of curculio activity. This indicates that control measures may be warranted in seed production areas, or where annual incomes from nut crops are desired. Continued research is needed in developing a sound control program to reduce the impact of this pest.

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PHYSIOLOGY AND SILVICULTURE OF BLACK WALNUT FOR COMBINED TIMBER AND NUT PRODUCTION

J. W. Van Sambeek and George Rink[1]

Abstract.--Research literature was reviewed for evidence supporting the management of black walnut plantations for combined timber and nut production. The silviculture of the species is discussed in relation to dual cropping. Stimulation and phenology of flowering and fruiting are reviewed.

Walnut growers face the same economic vagaries as other businessmen. The recent surges in the cost of capital have made standard economic forecasts obsolete. Current inflated interest rates may make plantation establishment costs prohibitive when projected over the length of walnut rotations. Nut crops could provide one source of early income to offset such costs (Kincaid and Kurtz 1981).

Industries marketing nut meats and shells would like a more regular yearly volume of nuts, although walnut is considered a fairly consistent bearer (Wylie 1966). Managers of seed orchards also need methods for enhancing nut production if they are to annually supply nurseries with genetically improved seed.

Evidence is presented showing that walnut can be managed for timber and improved nut yields.

MANAGEMENT STRATEGIES FOR TIMBER AND NUTS

Maximizing timber yield conflicts with maximizing nut yields. Maximizing production of quality timber requires greater stem pruning and closer spacing of trees to favor a longer branch-free bole, while increasing nut yield involves growing trees at a wider spacing to favor larger tree crowns. Optimizing both nut and timber production involves compromises in spacing as well as in timing and extent of pruning (Schlesinger and Funk 1977).

Initial tree spacing in plantations intended for combined nut and timber production is recommended to be 15 to 20 feet square compared to 10 to 12 feet square for timber alone. Planting trees at a close spacing provides more opportunity for selection of superior crop trees. It also necessitates an earlier thinning (Schlesinger and Funk 1977, Funk et al. 1978).

A criterion for determining the necessity and timing of thinning is crown competition factor (CCF). For nut production, the CCF should not exceed 90. A CCF of 90 means that the plantation will have to be thinned when the total crown area covers 90 percent of the plantation's land surface (Schlesinger and Funk 1977). The plantation may have to be thinned three or more times during a rotation. For example, in simulating an 80-year rotation, Foster and Kung (1980) proposed thinning a plantation six times. With a 20-foot-square spacing, the first thinning (around age 20) would be after the trees have begun flowering and fruiting. Crop trees could be selected on the basis of seed production, seed quality and stem form.

Lateral pruning should begin when the trees are 10 to 15 feet tall (approximately age 5) and should be continued in stages until more than 9 feet of clear stemwood is obtained on every crop tree. The length of clear stem should not exceed 50 to 60 percent of total tree height. Only crop trees need to be pruned. Corrective pruning will probably not be necessary because trees with poor form will be removed during thinnings (Schlesinger, in press).

No research data are available on combined nut and timber production from walnut plantations. Using simulation techniques, Foster and Kung (1980) compared the economic efficiency of managing for combined nut and timber production versus managing for timber alone. They found that managing for combined nut and timber production was more profitable than managing for timber alone, as long as the annual compound interest rate exceeded 6 3/4 percent and rotations were longer than 40 years. Similar conclusions have been made by Wylie (1966), Callahan and Smith (1974), Garrett and Kurtz (1980), and Kincaid and Kurtz (1981) using different economic and tree growth assumptions.

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Most projections for diameter growth assume it is a linear function of age with an average annual increment of 0.33 in/yr (Naughton 1970), 0.33 to 0.5 in/yr (Garrett and Kurtz 1980), or up to 0.56 in/yr (Wylie 1966). Projections for nut yields as a linear function of diameter at breast height for open-grown trees are illustrated in figure 1 (Foster and Kung 1980, Garrett and Kurtz 1980).

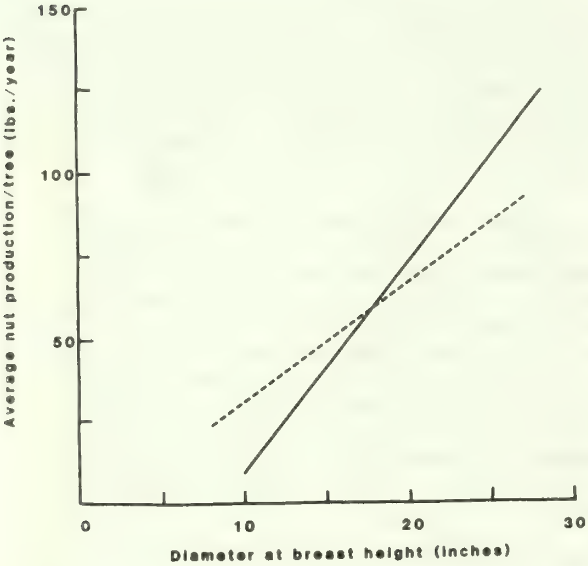

Figure 1.--Projections of average nut production by different diameter walnut trees. Solid line is for air-dried weight after Foster and Kung (1980); dashed line for freshly hulled weight after Garrett and Kurtz (1980).

One concern sometimes raised about combined timber and nut production is that potential tree growth may be diverted into a nut crop, possibly resulting in smaller trees. For apple trees (8 to 9 inches dbh) the stem cross sectional area lost due to fruit production is approximately 0.005 square inch per pound of fruit (Webster and Brown 1980). Because no such walnut data are available, it will be assumed that the reduction in walnut growth due to fruiting is similar to that of apples. According to Foster and Kung's projection (fig. 1), an 80-year-old walnut with an average annual diameter growth rate of 0.33 in/yr should produce about 3,100 pounds of air-dried, hulled nuts during its lifetime. This equals about 11,600 pounds of unhulled nuts (Funk and Polak 1979). Lifetime nut production will reduce potential stem diameter from 27.4 to 26 inches. This reduction equals 4 or 5 years of growth or about 18 board feet in the 8-foot veneer log. The value of the nut crop at current prices substantially exceeds the value of lost diameter growth for average grade walnut veneer logs. Shortening the rotation length can reduce both nut production and its potential effect on diameter growth.

Management guidelines are now available for improving diameter growth of black walnut on marginal sites (Schlesinger and Funk 1977). But what little information is available about improving nut yields has not been tested. Before we can reasonably expect to manipulate stands to improve nut yields, we must understand the physiology of flowering and fruiting for walnut. Most research on flowering and fruiting in Juglandaceae has been with English walnut and pecan, but it is assumed that much of this information also applies to black walnut.

FLOWERING BIOLOGY

Black walnut normally begins flowering about mid-April in the southern part of the range and mid-June in the northern part of the range, although within individual stands trees may vary by as much as a month in flowering dates (Masters 1974, McDaniel 1956). Flower development and leafing out occur at approximately the same time, early enough for possible damage by late spring frosts (fig. 2). Pollination and fertilization normally occur a few weeks after the mean frost-free date and are less likely to be affected by late spring frosts.

Walnuts bear separate male and female flowers on the same tree. Self-pollination is unlikely, however, because flowers of different sexes normally mature at different times; female flowers most often precede the males. However, spring floral development is definitely temperature dependent and warm temperatures at the time of flowering tend to increase the overlap between male and female flower maturation (Masters 1974).

Male flowers are found on wood grown in the previous season; they are initiated in vegetative buds during the period of rapid shoot elongation early in the growing season of the previous year. Female flowers are found at the tip of the current growing shoot, developing in dormant buds set after completion of the

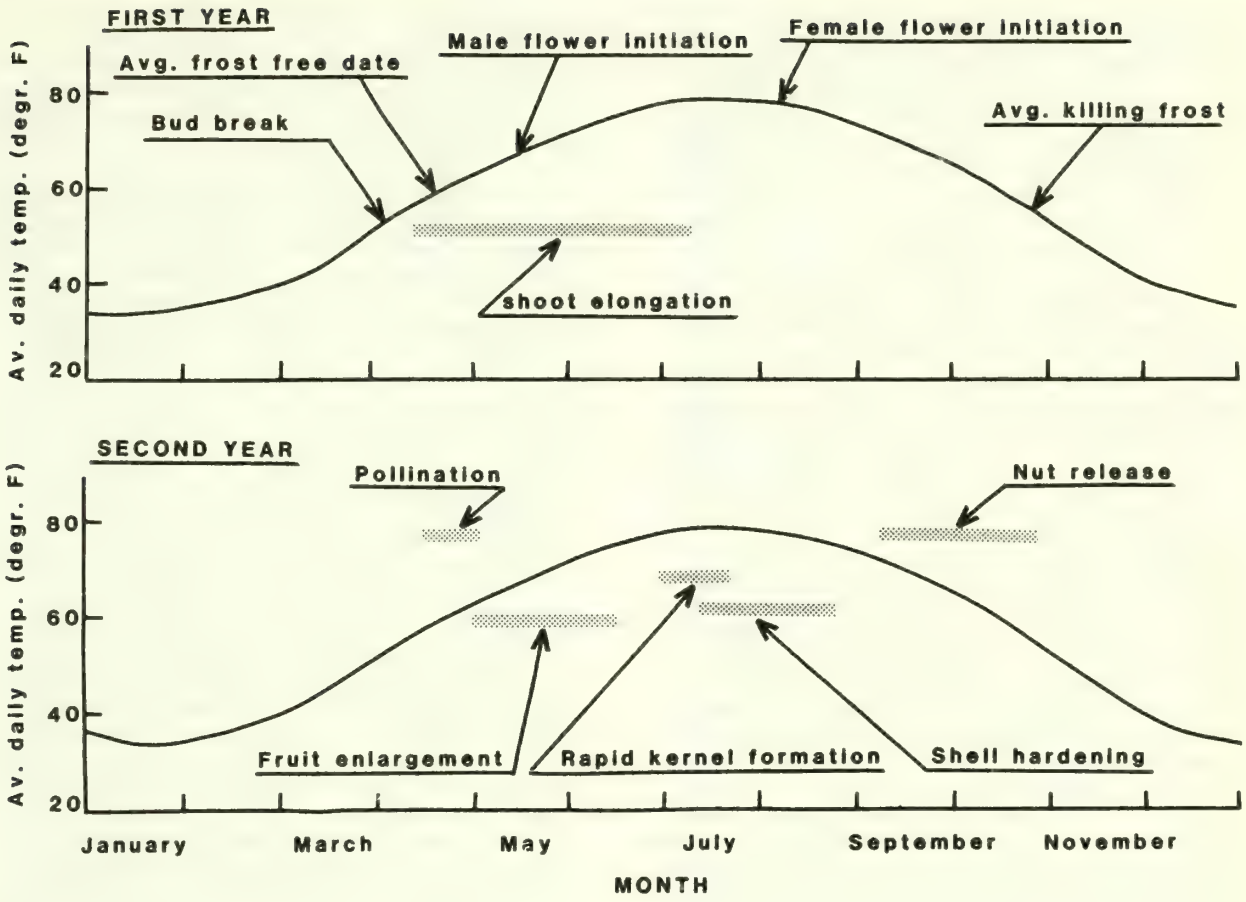

Figure 2.--Sequence of flower development, pollination, and nut maturation for black walnut in southern Illinois

previous year's growth (fig. 2) (Ramina 1969, Masters 1974, Funk 1978).

Several factors influence flowering abundance. All flowers are essentially borne on the crown surface. Any cultural practices increasing the crown surface area, or number of new branches, will increase the number of potential flowering sites. In English walnut the number of female flowers increases as growth is increased (Link 1961). Likewise, increased nut yields in black walnut in response to fertilization (Ponder 1979) and weed control (Holt and Voeller 1973) may be related to improved vigor resulting in more branches and branch growth and consequently more flower production.

Late spring frosts often reduce the number of flowers reaching maturity. Compared with clean cultivation, maintenance of leguminous or grass covers in walnut plantations may delay bud break by as much as 6 to 12 days, thereby decreasing the probability of damage to new growth and flowers (Wolstenholme 1970). Overtree irrigation in the spring will also delay bud break and flowering from 5 to 6 days (Beineke and Hunley 1979).

Little research has been done on the use of chemical sprays to alter new shoot growth and subsequent flower production. Marth and Mitchell (1961) found that gibberellin treatments promoted walnut shoot elongation. Foliar spray application may also increase flower production through improved branch growth. Langrova and Sladky (1971) found that auxin-containing sprays applied to English walnut when male flowers were forming decreased the number of catkins formed the following years; anti-auxin sprays applied after male flowers formed increased the number of catkins, many of which contained female flowers. The formation of male and female flowers is apparently controlled by the interaction of gibberellins, auxins, and growth inhibitors within the developing shoots (Sladky 1974). Further research is needed on cultural and chemical methods to stimulate flower formation and nut development.

FRUITING BIOLOGY

Fertilization occurs within 2 to 5 days of pollination, followed by a period of rapid expansion of the fruit during the next 5 to 6 weeks (fig. 2). Fruits increase in weight substantially before entering the shell-hardening stage in early July, although increases in size are not noticeable at this time. During the latter part of the shell-hardening stage (late July), the embryo and cotyledons begin to enlarge rapidly, incorporating most of the previously deposited endosperm. The kernel, composed of the embryo and cotyledons, usually does not develop until 4 to 5 weeks before the nuts are mature. By late August, some nuts can germinate after stratification. Most nuts, however, continue to increase in dry weight and do not drop from the tree until shortly after leaf fall in late September or early October.

Once the nutlets are formed, nutlet loss is usually due to disease or insect infestations. Blair and Kearby (1979) found that more than 50 percent of the potential nut crop in Missouri walnut plantations was destroyed by the walnut curculio. Epidemics of walnut anthracnose early in the growing season can cause significant nutlet losses; later or less severe disease outbreaks lead to poor nut filling and darkened kernels called ambers (Funk 1979).

Summer droughts can also lead to poor filling of the kernels and may also delay seed maturity (Batchelor et al. 1945, Crane 1949). Jones (1975) found that June, July, and August rainfall is an important variable in predicting annual nut crops in southwest Missouri. Irrigation during August and September may be important for high nut yields, because these months often include long dry spells.

Early fall frosts can injure new growth before it is completely lignified, preventing complete nut development and causing undesirable shrivel (Funk 1979). This frost danger is especially pertinent because recommendations for collecting seed 200 miles south of the planting site for greater timber production may result in immature nut crops (Sparks 1981). This problem may possibly be overcome by chemical treatment. In English walnuts, fall spraying with ethephon produces a mature nut crop 1 to 3 weeks sooner, and the sprayed trees produce higher quality nuts than the unsprayed trees (Martin 1971, Sibbett et al. 1974). Another alternative may be underplanting with leguminous winter annuals to accelerate tree dormancy (Auchter and Knapp 1937).

The minimum seed-bearing age for commercial quantities of nuts is about 12 years, although open-grown trees produce some seeds as early as 4 years after outplanting (Schlesinger and Funk 1977). The biggest challenge in managing walnut for timber and nut production is to maintain regular annual yields. On open-grown trees, nut crops are produced most commonly in an alternate-year cycle; some trees bear annually, others bear in 1 or 2 years out of 3, and many bear with no regular pattern at all (Zarger et al. 1969). Alternate bearing is characteristic of most fruit trees with late-season fruit maturation and is related to the carbohydrate concentration in the plant (Sparks 1979). Late-season kernel development makes a high demand on available carbohydrates and stored reserves when the new female flowers are forming. Increasing the leaf area per unit of fruit may decrease the alternate bearing tendency (Sparks 1979). Before thinning plantations, the manager may be able to identify those trees with good form that are persistent bearers or trees that produce crops during "off" years. Wylie (1966) suggested annually spot painting trees that have above-average nut yields for a period of 5 to 10 years before thinning to facilitate crop tree selection.

Nut quality should also be considered when selecting trees for yields. Kernel percentage, the dry weight of kernel as a percent of the dry weight of the entire nut, is the key factor in nut quality and should be more than 20 percent (Funk 1979). Such nuts can be expected to command a higher price (Garrett and Kurtz 1980).

CONCLUSIONS

Managing for nuts and timber requires a lower level of stocking than for timber alone to ensure rapid growth of large-crowned trees. The landowner must also prune trees to a minimum clear height of 9 feet and select for higher nut yielding trees before the last pre-commercial thinning.

Managers of seed orchards must select trees for rapid growth and nut production to provide landowners with the desired types. Also, they may have to select for late bud break and use techniques like overtree irrigation and herbaceous cover crops to delay bud break and flowering. Late-summer irrigation may be needed to ensure proper kernel development, and chemical ripeners may be used to ensure a harvest of mature nuts.

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NUT PRODUCTION--A VALUABLE ASSET IN BLACK WALNUT MANAGEMENT[1]

Harold E. Garrett and William B. Kurtz[2]

Abstract.--Black walnut nut production is a viable source of income for landowners involved in black walnut management. An evaluation of the impact of nut production on economic yields of two management options, timber vs. timber and nuts (timber option) and timber and wheat vs. timber, wheat and nuts (multicropping option) revealed greater economic returns from management regimes including nut production. Increases in internal rate of return (IRR) and present net worth (PNW) ranged from 0.5 to 2.2 percent and $438 to $2844, respectively, depending on management option and nut prices.

Eastern black walnut is regarded as one of the most valued of American native woods. Its wide use in the production of furniture, wall paneling, and gunstocks has resulted in substantial literature detailing the economic virtues of producing high quality veneer and sawlogs (Schlesinger and Funk 1977). However, little has been written on the economics of black walnut nut production. This is somewhat of an anomaly in view of the fact that one of the economic advantages of planting black walnut over other hardwood species is that it produces a marketable nut crop of considerable value. Although Mattoon and Reed (1924) suggested that "for the present the nut crop of the black walnut should be regarded only as incidental to the general farm operation--a by-product of the farm and not a staple crop," this does not hold in 1981. An available market for the sale of nuts exists in most states where black walnut is grown with the demand for nuts exceeding the supply.

With intensive management, black walnut will produce commercial nut crops on all sites by age 20 and will produce commercial crops on many by age 15. In recent years nut values have ranged from $3-$5.00 per hundred pound weight (cwt) for nuts collected from native groves. However, as high as $24.00 per cwt. has been paid for plantation-grown nuts. Differences in prices arise from differences in percentage crackability. Nuts from natural stands, under commercial processing, yield an average of only eight pounds of kernels per cwt. of hulled nuts. With plantation conditions, a yield of 20 or more pounds of kernels per cwt. is projected at a significantly higher value.

To evaluate the economic importance of nut production in walnut management, potential gains with and without nuts from two basic management options (timber and multicropping) are compared.

MANAGEMENT ALTERNATIVES AND ASSUMPTIONS

There are countless walnut management options which can be designed to accomodate the objectives of the landowner within limitations of the site. For the purpose of evaluating the impact of nut production on economic yields a comparison was made within two basic options: timber vs. timber and nuts (timber option) and timber and wheat vs. timber, wheat and nuts (multicropping option). These alternatives were developed using conditions relating to black walnut production in Missouri but are applicable throughout the natural range of the species. Factors considered are site quality, diameter growth rate, number of trees planted per acre, pruning height and thinning regimes. The reader is referred to Kincaid et al. (1981) for specific details on these factors.

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[1] Paper presented at the Walnut Council/ NNGA Symposium, West Lafayette, Indiana, August 9-14, 1981.

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For this comparison site quality and rotation length are held constant. A site index of 80 is assumed with a projected average diameter growth rate of 1/2-inch per year. A rotation length of 60 years was selected for all management alternatives. Thinning recommendations are based on projected diameter classes and crown competition factors (CCF-Schlesinger and Funk 1977) resulting in precommercial and commercial thinnings.

Timber

Black walnut is a species of great genetic variation. Because of its variability, it is important in timber production to utilize a close spacing, securing selection gain through thinning. While the spacing may vary with site and specific management objective, a spacing of 12 x 12 feet (300 stems/acre) has been selected for this analysis. Forty trees are selected for a first pruning to a height of nine feet at age eight. A second pruning of 27 crop trees (to be selected from the original 40) is conducted at age 16 to a height of 17 feet. Through selective thinning, the number of trees are reduced to 27 (approximately 40 x 40 feet) by rotation end. A maximization of log quality is achieved through artificial pruning.

Timber and Nuts

Growing walnut for timber and nuts requires the use of a wider spacing than growing trees for timber alone. This is important to develop a large, relatively uninhibited crown. Therefore, a 40 x 10-foot spacing providing 108 trees per acre was selected. As in timber production, selection gain is achieved through precommercial and commercial thinnings applied to reduce the number of trees to 27 by age 33. Clear-length pruning within this regime differs from the pure timber regime in that the management objective is a shorter log with greater emphasis placed on crown size for nut production. At age ten, 40 trees are pruned to a height of 9 feet. As in the timber management regime, 27 crop trees are selected for a second pruning. Pruning occurs at age 20 and extends the clear length of the stem to 15 feet.

Nut prices are projected at $5,00, $9.00, $15.00 and $20.00 per hundred pound weight of hulled nuts. The prices are conservative in view of the fact that $24.00 per cwt has been paid in recent years for plantation grown nuts (personal communication, Gus Rutledge, Hammons Products Co., Stockton, Missouri). However, it provides a reasonable range of prices to cover a fluctuating market. Nut yields (Table 1) are also intentionally conservative in an attempt to offset the unknown cost of harvesting.

Table 1.--Projected nut yields from black walnut under plantation management.

Avg dbh (inches)	Estimated yield[1] (pounds of hulled nuts/acre)
11.0	2128
13.5	2286
15.5	2238
18.5	2937
22.5	2937
27.5	2916
32.5	2916

[1] After Kincaid, W. H., 1981. Economic-silviculture aspects of black walnut management, M.S. Thesis, School of Forestry, Fisheries and Wildlife, University of Missouri-Columbia. (Yield estimates derived by linear regression from Zarger (1946) and increased by fifty percent to account for increased yield from plantation management.)

Timber and Wheat

A timber and wheat management regime assumes plantation establishment and management practices similar to those of the timber and nuts alternative--i.e., number of trees per acre, thinning schedules, pruning heights, growth and nut yields are unchanged. However, an intercrop of winter wheat is grown between walnut rows for the first ten years. Although wheat could be produced over a longer period without significant yield reductions resulting from walnut competition, in our analysis it is projected for only ten years due to practical considerations relative to management. In growing wheat, a minimum of three feet is left between the crop and trees. This land is removed from production to minimize competition in the early spring and to reduce damage to the walnut root system that might occur during site preparation.

Timber, Nuts and Wheat

Timber and wheat establishment and management practices, and costs and revenues are the same for both the timber, nuts and wheat and timber and wheat regimes. However, the timber, nuts and wheat regime does have the additional benefit of nut yields which are assumed to be the same as from timber and nuts.

ECONOMIC EVALUATION

The economic contribution of nut production to a black walnut management scheme was assessed by comparing the internal rates of return (IRR) and present net worth (PNW) generated by cash flows from the two basic management options with and without nut production. As indicated previously, nut prices of $5.00, $9.00, $15.00 and $20.00 per cwt. were used in evaluating the two options that included nut production. All other prices are the same as those shown in Kincaid et al. (1981). Walnut stumpage prices for commercial thinning and final harvest material were inflated at an annual rate of 1.5 percent (Hoover 1978).

Greater economic returns were realized from those management regimes including nut production (Table 2). For both the timber and the multicropping options nut production accounted for an addition to IRR of from 0.5 to 2.2 percent depending on nut prices. In a similar fashion, increases in PNW ranged from $523 to $2844 per acre for the timber option and from $438 to $2598 per acre for the multicropping option. The slightly higher levels of difference in PNW for the timber option over the multicropping option are due to the additional costs incurred in establishing and precommercially thinning the extra 192 trees required in the timber regime--costs that are not offset by the greater stumpage yields for commercial thinning and final harvest in the timber regime.

With increased nut prices, the respective IRRs for the two regimes including nut production would increase by 1 to 6 percent over the $5.00 to $20.00 per cwt. price range (Table 2). For the timber and nuts regime an increase in PNW of $2321 per acre and for the timber, nuts and wheat regime an increase in PNW of $2159 per acre would result from the increase in nut prices. Obviously, the resultant increases in the financial return measures are linked directly to the expected nut yields of the respective regimes.

The sensitivity of IRR relative to changes in nut yields was examined to determine the effects of such variations on the stability of IRR for the two regimes incorporating nut production (Table 3). Since IRR is conditioned by product price, it becomes more sensitive to nut yield changes as nut price is increased. For example, at the lower nut price of $5.00 per cwt. annual nut yield would have to be increased by well over one-and-one-half times for either regime to increase IRR by one percent. In contrast, at a nut price of $20.00 per cwt. annual nut yields would only have to increase by just over one-half to increase IRR by one percent.

Conclusions

Management of black walnut stands for nut production in conjunction with timber production or a multicropping alternative is clearly to one's financial advantage. Higher returns are yielded by those management regimes incorporating nut production in comparison to those which do not. Depending on assumed nut price, increases in PNW of from $400 to $2900 per

Table 2.--Internal rate of return[1] (IRR) and present net worth[2] (PNW) of four alternative black walnut management regimes at nut prices of $5, $9, $15, and $20 per cwt.

Management regime	$5		$9		$15		$20	
	IRR	PNW	IRR	PNW	IRR	PNW	IRR	PNW
	(Pct)	($ per ac.)	(Pct)	($ per ac.)	(Pct)	($ per ac.)	(Pct)	($ per ac.)
Timber	6.68	2471.94	6.68	2471.94	6.68	2471.94	6.68	2471.94
Timber and nuts	7.27	2994.74	7.71	3613.65	8.33	4542.03	8.81	5315.67
Timber and wheat	8.20	3344.89	8.20	3344.89	8.20	3344.89	8.20	3344.89
Timber, nuts and wheat	8.74	3782.68	9.23	4358.62	9.91	5222.52	10.42	5942.44

[1] Internal rate of return is the average interest rate earned on all costs up until the time of investment maturity.

[2] Present net worth is the net value of the stream of costs and revenues discounted back to the present at a 5.0 percent interest rate.

Table 3.--Sensitivity[1] of internal rate of return to changes in nut yields for two black walnut management regimes at nut prices of $5, $9, $15 and $20 per cwt.

Management regime	$5	$9	$15	$20
	Percent			
Timber and nuts	189.33	110.57	72.08	58.15
Timber, nuts and wheat	168.35	101.14	68.52	56.79

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[1] Sensitivity is expressed as the percent increase in annual nut yield required to increase internal rate of return by 1.0 percent.

acre may be attributable to the value of nuts produced over the 60-year rotation.

Nut production in a multicropping regime --timber, nuts and wheat, in this instance-- offers the greatest financial returns of those alternatives considered due to the earlier returns from crop yields, later supplemented by nut yields. In comparison to the timber and nuts management regime, the multicropping regime including nuts generates additional PNW of $600 to $800 per acre depending on assumed nut prices.

The financial success of managing for nut production is directly linked to the price of nuts. Obviously, the higher the price received the more profitable will be management for nut production. Although not completely supportable, given the present and the anticipated supply-demand situation for black walnut nut meats, it is quite likely that the price paid for quality hulled nuts will experience a continued rise.

Our view is based on the many potential uses for hulls, and nut meats as well as current market requirements which are not being met. In good crop years, Hammons Products Company, Stockton, Missouri, the Gravett Shelling Company, a Division of Hammons Products, Gravett, Arkansas, and Funsten Nut Division of Pet, Inc., Bolivar, Missouri, the major purchasers of eastern black walnut nuts attempt to buy a total of approximately 60 million pounds of hulled nuts. Only rarely is this achieved. In 1980, only four million pounds were available for purchase. Since eastern black walnut nut meat is presently sold only as a flavoring agent and little or no consideration has been made for its nutritional value, the extractable fat from the nut meat or the export market, the potential market for eastern black walnut kernels has hardly been tapped. In light of this, a market demand of 200 million pounds per year is not considered to be unrealistic.

These are encouraging results for black walnut growers. By emphasizing nut production, an additional reliable source of income is available for the majority of the rotation period.

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THE STATUS OF BLACK WALNUT TREE IMPROVEMENT PROGRAMS IN THE NORTH CENTRAL REGION

George Rink and Henry E. Stelzer[1]

Abstract.--Black walnut was found to be a high priority species for improvement in Central and North Central United States. Most State improvement programs have as their goal the ability to meet seedling requirements with improved seed. States included in this report may have orchard acreage sufficient to meet this goal. Anticipated year of production of improved seed from seed orchards and seedling demand projections are presented by States.

INTRODUCTION

Genetic improvement of black walnut has been advocated for at least 20 years. Although Wright (1966) outlined several approaches to such improvement, he felt that a basic improvement program to include selection, provenance, and progeny testing would be the most efficient and productive approach in the long run.

Although the feasibility of genetic improvement of walnut is fairly well documented by research, the application of research results has apparently lagged behind (Bey 1973, Funk 1973). However, walnut action tree improvement programs now exist and it seems that large-scale production of improved walnut seedlings will be a reality soon.

Most tree improvement programs have as their primary goal the production of faster growing, pest resistant trees with better form for increased timber yield. Such improvement is accomplished by identifying and selecting the best trees and propagating them in seed orchards. Seed from such orchards are used to produce improved nursery stock for future reforestation. From this standpoint the ability of these improved trees to produce nuts is critical. The essential concept of an orchard involves using trees of known high genetic potential for seed production as opposed to buying or collecting seed from perhaps unseen and certainly untested trees.

INFORMATION SURVEY

Questionnaires were mailed to 11 State agencies or universities in the commercial range of black walnut requesting information on current status and future plans for the species. States included in this informal survey were Illinois, Iowa, Indiana, Kansas, Kentucky, Michigan, Minnesota, Missouri, Ohio, Tennessee, and Wisconsin. Although other states in the East and Northeast produce walnut seedlings, most of their activities are centered around growing walnut in an urban setting or for nut production. These States have small areas that would qualify as classical walnut sites and their seedling production is usually lower than in the Central and North Central States. Consequently, walnut tree improvement efforts have a lower priority in the East and Northeast and they were not included in this survey. Additional information was provided by USDA Forest Service, State and Private Forestry.[2]

RESULTS

All 11 States were involved with walnut improvement, although the level of involvement varied from State to State. The least intensive level of involvement was represented by cooperation in provenance/progeny testing, while the highest level involved actual orchard design and progeny testing with plans for creating second generation orchards. Most programs may be described as basic improvement programs (Wright 1966).

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[2] Verbal communication, Mr. Clyde M. Hunt, Broomall, PA, June 1981.

Most responses to the questionnaire indicated high priority for walnut improvement and five States ranked walnut as the number one priority species (table 1). Many respondents also indicated that their long-term goal was to have all State nursery production of walnut from improved seed.

Responses reflect two basically different approaches to seed orchards--clonal vs. seedling. In a clonal walnut orchard, selected trees are propagated by grafting while seedling seed orchards are created by planting seed of select trees and subsequently thinning the resulting stand to retain only the best phenotypes for seed production.

In many cases, there is a fundamental philosophical difference between the two approaches. The clonal approach usually relies upon the belief that a certain amount of gain can be achieved by selecting superior trees in the wild and vegetatively propagating such trees. For example, Indiana, Kansas, and Kentucky rely upon selecting trees on the basis of growth rate, straightness, branch angle, bole quality, and apical dominance; trees are selected and cloned if they are above average to superior in all or most of these traits. This approach is most common with tree species growing in even-aged stands. Selection is on the basis of comparison of these traits with neighboring trees. However, due to the scattered distribution of walnut and its habit of growing in uneven-aged stands, such comparison tree selection schemes may not be reliable or efficient. As a result, selection of walnut in the wild is usually empirical, with no formal grading system.

By contrast, the seedling seed orchard approach is one selected by Iowa, Wisconsin, Minnesota, and USDA Forest Service. By this approach, single tree nut collections are used to create progeny tests. Mother trees from which nuts are collected for progeny tests are not rigorously selected; usually they are stipulated to be only of average or better quality. Rigorous selection at this stage is avoided because it is felt that there is no way to evaluate single trees for important traits without even-aged neighbor trees growing on a similar site under similar conditions. In this approach rigorous selection is carried out at the progeny test stage.

Actually, the differences between the two approaches are not clearcut because selected trees are usually progeny tested in the clonal approach, too. Final selection for seed orchard inclusion is usually withheld until progeny test results.

The two States with the most advanced walnut improvement programs are Indiana and Missouri. Both States expect to be producing improved seed from their first generation orchards by 1985 and both list black walnut as their first priority species.

The Indiana program is the oldest State-operated walnut improvement program. It is a coordinated effort between the Indiana Department of Natural Resources and Purdue University. This program has placed more emphasis on selection of wild trees than in any other State. Selections have been propagated in a clone bank and approximately 100 of 250 original selections are being progeny tested. Based on performance

Table 1.--Summary of responses from informal survey mailed to 11 States

State	Seedling seed orchard[1]	No. families	Clonal orchard[1]	No. clones	Progeny test	Anticipated date of orch. prod.	Current seedling prod. target	Priority
	(Acres)		(Acres)		(Acres)			
Illinois			30	60+		1990	500,000	1
Iowa	10	130			10	1995	700,000	1
Indiana			40	35	11	1985	300,000	1
Kansas			37	85	2	1987	125,000	1
Kentucky			10	9		2000	300,000	#1 hardwood
Michigan					18		100,000	high
Minnesota	7	150			7	1990	300,000	2
Missouri	73	144	10		73	1985	500,000	1
Ohio	0		0		15		250,000	low
Tennessee							0	high
Wisconsin	7	150	0		7	1988	300,000	#1 hardwood #5 overall

[1] Actual acres presently in orchard or in the midst of establishment.

in the clone bank and progeny test, 35 of these have been propagated in seed orchards. Second generation orchards are being planned from selections to be made from progeny test results.

The Missouri Department of Conservation program consists of 73 acres of Statewide progeny tests to be converted to seedling seed orchards by roguing the poorest individual trees and families. When the progeny testing is complete, superior genotypes will be combined into a clonal orchard.

Both Indiana and Missouri plan to maintain original selections in clone banks.

In Kansas, responsibility for walnut improvement rests with the Department of Forestry, Kansas State University. Although their seedling requirements are modest, the program is well underway with two established clonal orchards. The Illinois Department of Conservation and Natural Heritage is also in the midst of establishing two clonal orchards. These orchards will consist of selections from existing USDA Forest Service and Indiana Department of Natural Resources progeny tests.

The Iowa program is administered by the Iowa Conservation Commission. The program consists of two 5-acre progeny tests of 130 plus-trees selected throughout the State. The progeny tests were established in 1976 and are intended to serve as seedling seed orchards after roguing. These areas may have to be expanded by grafting to meet seedling production needs.

Both Kentucky and Tennessee walnut improvement programs are in the early stages of establishment. The Kentucky Division of Forestry has established 17 acres of regional and Statewide provenance tests that will serve as an interim seed source until a clonal orchard is established. Selection of superior phenotypes for the clonal orchard has already been initiated. The Tennessee Division of Forestry expects to begin walnut seedling production in 1982 and within 5 to 10 years anticipates production in excess of a half million seedlings per year. An orchard is being planned from expansion of a clone bank containing 50 plus-tree selections as well as incorporation of 66 selections in a Tennessee Valley Authority clone bank. Progeny testing will accompany seed orchard construction.

The walnut improvement programs of the Minnesota and Wisconsin Departments of Natural Resources are similar. Both call for 7-acre progeny tests to be converted to seedling seed orchards. Walnut is a second priority species in both States.

Both Michigan and Ohio are involved in cooperative USDA Forest Service provenance/progeny tests. Michigan has no plans for walnut seed orchards, while Ohio already has 15 acres of progeny tests in various parts of the State to be converted to seed orchards. Some of these Ohio tests were established in 1969 and should be producing seed soon if they are properly managed. Unfortunately, the State has no overall tree improvement program so these progeny tests may be neglected.

The USDA Forest Service has identified black walnut as a first priority species for tree improvement in the Central States. Walnut improvement in the USDA Forest Service is primarily the responsibility of the North Central Forest Experiment Station and the National Forests in the Central States. Progeny tests have been established on the Shawnee, Wayne, Hoosier, and Monongahela National Forests in the 1973-1976 period with the objective of conversion to seed orchards for National Forest walnut regeneration. Trees being progeny tested are of average or better quality from seed zones delineated for each National Forest; a minimum of 50 trees are included in each progeny test. In addition, the North Central Forest Experiment Station has established two progeny tests for conversion to seed orchards for the State of Illinois. These tests include 87 families. These progeny tests will probably be producing improved seed by 1990.

THE OUTLOOK FOR THE FUTURE

In 1966 Funk described an idealized hypothetical black walnut seed orchard. According to Funk's (1966) calculations, an orchard with 20-foot square spacing should be able to produce 30,000 seeds per acre in the "on" year and assuming an 80 percent seedling percent this would translate to 24,000 seedlings per orchard acre in good years. This means that a 10-acre orchard should average approximately 250,000 seedlings at least every other year. Using these figures as a crude, conservative guideline, it is clear that most States that list walnut as their first priority species already have orchard acreage that may meet their seedling needs upon maturity (assuming a 20-foot square spacing, which is probably too close). The one exception to this is Iowa, which has the highest seedling requirement but only 10 acres of orchard. Iowa's orchard acreage should be at least 3 to 4 times greater if all seedling production is to be from improved seed.

One source of concern is the fact that apparently many selections are not being adequately progeny tested. Acreage listed in table 1 for progeny tests seems rather low considering how many selections have been made and the number of orchards being established. Without good progeny tests, it will be difficult to demonstrate potential gains by using improved growing stock.

Nevertheless, improved walnut stock will be a reality in the near future. Once it is shown that improved walnut seedlings are pest resistant and have better form as well as providing higher survival and growth, demand for seedlings will likely increase dramatically. Conservative projections indicate possible growth gains of from 15 to 30 percent over current nursery stock by using first generation selections. An added improvement of that magnitude should be possible in subsequent generations.

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INDIANA DIVISION OF FORESTRY BLACK WALNUT TREE IMPROVEMENT PROGRAM [1]

Mark V. Coggeshall and Stephen G. Pennington [2]

Abstract - The State of Indiana black walnut tree improvement program is a cooperative effort between the Department of Forestry, Purdue University and the Indiana Department of Natural Resources, Division of Forestry. The program steps include phenotypic selection, clone bank evaluation of selections, half-sib progeny testing, and clonal seed orchard establishment.

The Indiana Division of Forestry initiated a black walnut (Juglans nigra L.) tree improvement program in 1971. The program can be characterized as a half-sib progeny test, clonal seed orchard approach. A clone bank is included. The goal of the program is to insure that black walnut seedlings distributed by the two state nurseries will provide the best performance possible when outplanted by Indiana landowners. Specifically, there are four program objectives: 1) to preserve the highest quality specimens of black walnut trees in Indiana by grafting their genotypes into the clone bank and state seed orchards; 2) to counteract the effects of dysgenic selection by re-introducing the offspring of these superior genotypes into Indiana woodlands through seedling distribution from the state nurseries; 3) to develop tree varieties that exhibit a high genetic potential for such characteristics as growth rate, form, and disease resistance; and 4) to provide a continuous supply of seed from this improved stock for the state nurseries.

The following steps are included in the Indiana black walnut tree improvement program: selection of superior phenotypes, establishment of all selections in the clone bank, half-sib progeny testing of the selections, and cloning the best selections into state seed orchards. This paper summarizes our efforts to date for each of these activities.

CURRENT STATUS

Annual seed requirements for the two state nurseries is approximately 750,000 walnuts. An average germination rate of 50 percent and a cull rate of 20 percent yields 300,000 seedlings annually. Seed is presently collected by nursery personnel and other Division of Forestry properties with little regard for parent tree quality, especially in poor seed years.

The Indiana black walnut tree improvement program will supply high quality seed to the state nurseries by insuring that superior genotypes are the seed sources for the nurseries in the future. The rationale for using the half-sib, clonal seed orchard approach with a clone bank is addressed by Masters and Beineke (1972). Each of the steps in the black walnut tree improvement program are addressed below.

SELECTION OF SUPERIOR PHENOTYPES

Approximately 250 superior phenotypes have been selected from the natural black walnut population in Indiana. Most of these trees were graded on a point system for such characteristics as growth rate, apical dominance, straightness, and habitat (W.F. Beineke, personal communication). However, environment can influence these traits and some superior phenotypes have been found to be genetically inferior when progeny tested. As a result, comparison tree selection in plantations has lately received more emphasis. The majority of the newer selections now included in the program are from plantations or open-grown locations. New selections have also been made in older half-sib progeny tests established by Purdue University and the Indiana Division of Forestry. To date 13 recurrent selections are included in the program.

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[1] Paper presented at the 1981 Joint Meeting of the Walnut Council/Northern Nut Growers Association, West Lafayette, Indiana, August 9-14, 1981.

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PURDUE CLONE BANK

Selections that have been accepted into the program are grafted and placed in the clone bank at the Purdue University Martell Forest. The purpose of this clone bank is fourfold: 1) to gain an insight into a selection's performance in future seed orchard situations (ie growth rate, flower production); 2) to evaluate the ease by which a selection can be grafted; 3) to provide a source of easily obtained scion wood for use in the production of grafted trees for the state seed orchards; and 4) to preserve the genotypes of the best quality specimens of black in Indiana. The clone bank is maintained by Purdue University.

Purdue University has been conducting black walnut genetics research, especially in the areas of selection, flowering, and progeny testing, since 1968. The results of this research has led to the incorporation of tested clonal material into state seed orchards. The Indiana Division of Forestry is fortunate to have this cooperative arrangement with Purdue University whereby intensive research efforts will result in direct benefits to the Indiana landowner.

HALF-SIB PROGENY TESTING

The purpose of a half-sib progeny test (male parent unknown) is to evaluate the selections based on the performance of their seedling offspring. Progeny testing provides information on the genetic value of the selections. In addition, recurrent selections can be made in older progeny test plantations.

Seed collected from the selections (both original parent trees and older clone bank individuals) are sown at the Vallonia Nursery and outplanted as 1-0 stock at various locations throughout Indiana (fig. 1). A total of 19 progeny test plantations representing 67 selections have been established at 12 sites since 1969 by Purdue University and the Indiana Division of Forestry.

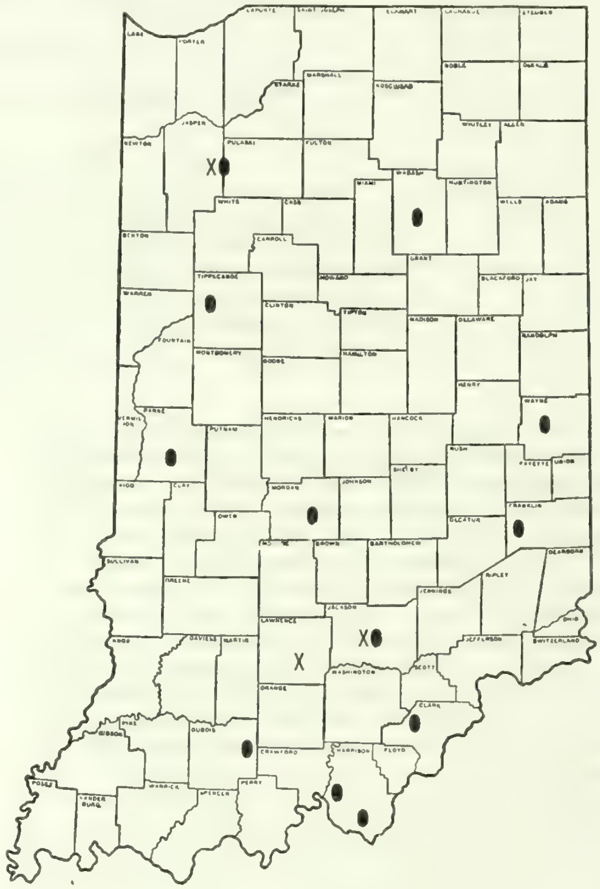

Figure 1.-- ●= Locations of half-sib progeny test plantations in Indiana established by Purdue University and the Indiana Division of Forestry. X= Locations of state seed orchards.

Since 1979 progeny tests have been planted at a spacing of 4 X 4 feet (Coggeshall and Beineke, 1979). These close-spaced, short term progeny tests were established to evaluate juvenile height growth. Kung (1973) used stem analysis from 30 year old black walnut trees to produce juvenile-mature correlations. He found that the correlation between juvenile height and cubic foot volume at 30 years reached a plateau at age 3. In addition, McKeand (1978) reported that family rankings for height growth in previous Indiana progeny tests stabilized by age 4. The tallest families at age 4 were also the tallest at age 9. Therefore, short term progeny testing is valid for black walnut. Rapid screening of families is essential because black walnut produces highly variable seed crops and new selections are constantly being added to the program making annual progeny test establishment necessary. Good black walnut sites at both state nurseries and at the Purdue University Martell Forest have been designated as progeny test areas.

There are several advantages to short term progeny testing. Less site variation will be encountered by planting at such close spacing and weed control problems common to standard progeny testing will be reduced. Also landowner interest will be intensified when planting fast growing planting stock is made available from the state nurseries.

CLONAL SEED ORCHARDS

A seed orchard is a collection of selected trees established and grown together under intensive management for mass production of genetically improved seed. Cloning achieves the result of bringing intensively selected, but widely scattered trees to a common location in their original genotypes. Higher genetic gains can be realized by using this approach (Masters and Beineke, 1972). Each selection is replicated several times in the seed orchard and arranged so as to maximize outcrossing. Selections are grafted into the seed orchards based on progeny test results and the performance of grafts in the clone bank- form, foliation dates, and fecundity. Many excellent clones are not included in the orchards because of poor nut production.

Thirty-four acres of clonal seed orchards have been established in 3 locations throughout the state (fig. 1). Seed orchard establishment began in 1970. Approximately 30 to 40 clones have been selected from the 250 original selections to be included in the seed orchards and 20 to 25 clones are being propagated annually at Vallonia.

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NEW DIRECTIONS IN GENETIC IMPROVEMENT:

GRAFTED BLACK WALNUT PLANTATIONS[1]

Walter F. Beineke[2]

Abstract.--Black walnut produces fewer seed per tree than most tree species which leads to problems of providing sufficient seed from traditional seed orchard production of genetically superior planting stock. Seedlings seldom capture the full complement of genetic improvement possible from parent trees particularly when the male parent is unknown or inferior.

Vegetatively propagated plantations provide a method to take advantage of the complete potential improvement of an improved selection. Patenting and licensing provide protection for researchers who have invested time and money in developing and proving superiority.

Gains in height, diameter, and form are discussed as well as risks from monoculture and containerized planting.

INTRODUCTION

Authors of past Walnut Symposium articles on tree improvement have predicted promising results from the genetic manipulation of black walnut (Bey 1973, Brunk 1973, Funk 1966, Funk 1973, and Wright 1966). Geneticists have cut years from the projected time needed to produce improved stock, but we are still 10 to 15 years from producing significant volumes of improved black walnut seed.

Improving trees through genetics is long-term and black walnut poses some particularly vexing problems (Beineke 1979). Walnut, unlike pines, cottonwood, sycamore, sweet gum, and many other species, is not a prolific seed producer. While a pine tree can produce many thousands of seed each year, most walnut trees produce, at best, only several hundred seed, and pests can claim a large share of those. From the remaining seed, nurserymen routinely obtain only 50 to 60 percent germination.

The number of nuts produced per tree can be increased by selecting good nut producers, wide spacing, fertilization, and weed control, but walnut still requires many years to produce quantities of seed and never approaches the prolific seed production of the light-seeded species. Thus, seed orchard programs for black walnut must provide for this lack of seed production with increased seed orchard acreage and improved management.

SEEDLING VS. CLONAL PROPAGATION

Seedlings are the product of pollination and fertilization, a sexual process, and are genetically different, just as brothers and sisters differ, even though they have the same parents. Of course, siblings usually do have some resemblance to their parents and to each other, but they are variable. That portion of variation is one source of inherited improvement--the additive portion. That is the only portion that can be depended on to provide improvement when sexual reproduction is used.

On the other hand when grafting or other means of vegetative reproduction is used, all of the genetic potential (non-additive plus the additive portion) of the superior tree can be passed on to the next generation (Libby 1977). That is, a graft is an exact genetic duplicate (clone) of the selected tree containing all of the improvement possible from the aboveground portion of the parent. For some traits such as volume growth, having low additive inheritance, Zobel (1981), states that, "it appears possible to more than double short-term genetic gain by using vegetative propagules rather than seed regeneration."

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[1] Paper presented at the Walnut Council-NNGA Black Walnut Symposium, Purdue University, West Lafayette, IN. August 9-14, 1981.

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Once a superior tree is identified and tested for a sufficient time, it can be multiplied by vegetative propagation at a fairly young age without waiting for seed production to occur. In the first 12 years it is estimated that nearly 10 times more plants can be reproduced from a young walnut by grafting than from seed (table 1).

Table 1.--Estimates of average numbers of propagules available from walnut clones at various ages.

Tree age/ year	Numbers of seed produced	Numbers of grafting buds produced
1	0	0
2	0	5
3	0	15
4	3	50
5	7	100
6	10	200
7	15	350
8	30	500
9	60	650
10	110	800
11	130	1000
12	150	1300
Total	515	4970
Average	43	414

Also, nut production in black walnut tends to be cyclic with most trees producing large crops only once in 2 to 4 years, and the crop may be subject to frost and insect damage every year. That is why average yearly nut production does not rise sharply after the first few years (table 1). In contrast, new branches having graftable buds grow every year. Even following years of slow growth, large amounts of grafting wood are available; especially from trees pruned vigorously and annually.

Genetic uniformity in tree size, form, nut production and wood properties is a positive factor in favor of clonal propagation. Economic advantages accrue in the marketing and harvesting of uniform stands (Zobel 1981).

At the present time, the only operational, practical vegetative propagation technique for black walnut is by grafting (Beineke and Todhunter, 1980). However, two other methods may show promise in the future - rooted cuttings and tissue culture.

Rooting of cuttings is a commonly used method to propagate many plant species. Major advantages of rooted cuttings are that the plant is supported by its own genetically compatible root system and is cheaper than grafting. With few exceptions, (Carpenter 1975, Farmer 1971, Shreve and Miles 1972), rooting of black walnut cuttings has proven to be extremely difficult. Cuttings require a length of stem, usually with a terminal meristem intact, thus greatly reducing the number of propagules obtained from a tree compared with grafting. In black walnut the same length of stem used for one cutting could produce three or four grafts.

Tissue culture, a fairly new tool, is emerging as a revolutionary vegetative propagation technique for many species (Murashige 1974, Durzan and Campbell 1974). Briefly, tissue culture in black walnut would probably involve removal of a vegetative bud from a superior tree and placement on a sterile growing media in a petri dish. Subsequent bud growth and shoot elongation would produce lateral bud formation along the shoot. Each of these lateral buds would then be excised and placed on media to grow and multiply proliferating a single bud into hundreds or thousands of plantlets. Shoots for operational planting would have to be placed on special rooting media to induce root formation and growth. Plantlets would then be transferred to containers and moved to the greenhouse and hence to the field.

Each step in this process has an incredible array of problems to be solved and, at present, is strictly theoretical. However, it has been accomplished for roses, apples, loblolly pine, and a few other woody species (Hasegawa 1979, Huth 1978, Mott and Amerson 1981). The advantages of this technique are, of course, the unlimited number and rapid propagation of an improved cultivar from a few buds. Once techniques became operational, tissue culture would probably be cheaper than grafting (McKeand 1981).

PATENTING

The use of vegetative propagation provides an opportunity to patent improved clones. Plant patents grant protection from indiscriminant propagation of improved material. The rationale behind patenting is that the developer who took the risks and funded the work should have the opportunity to profit without competition from those who did not have the foresight to provide funding for the development of the new material. To obtain a plant patent, the "unique" attributes of the plant must be proven. Note that "genetic improvement" is not necessarily a criteria for patenting. Proving a tree unique is a time-consuming, difficult and expensive process which involves comparisons of traits with known or previously patented material of the same species.

Patenting black walnut for timber purposes had never been previously attempted until the patents on Purdue 1, 2, and 3 were issued. After the patent is granted, the patented tree can be licensed for propagation and sale to the public. Purdue 1, 2, and 3 were patented by and licensed for propagation through the Purdue Research Foundation. This arrangement allows the University to collect royalties on the sale of each tree, thus obtaining some return on its investment in research.

The grafted clone approach differs greatly from the seed orchard approach outlined in previous papers at this symposium. The use of buds rather than seed is the basis of propagation and involves several additional items - i.e., budwood collection, storage, and care. Seedling production requires only the standard nursery installation. Grafted black walnut requires much more investment in production facilities such as greenhouse, propagation areas, potting equipment, grafting materials, budwood storage, holding areas for completed grafts, and skilled technicians to do the grafting in addition to the standard nursery to produce rootstocks for grafting.

GENETIC GAINS

How much gain can be expected using vegetative propagation rather than seedling reproduction? Unfortunately, large, well-designed, older tests are not available to study this crucial aspect. However, from our older tests containing seedlings from patented Purdue 1 vs. a nursery-run check and grafted patented Purdue 1 vs. a nursery check, some rough estimates can be made (table 2). The seedling test is located in southern Indiana, while the clonal test is at Martell Forest near West Lafayette, in central Indiana. Therefore, differing soils and climatic factors apply. The southern Indiana seedling test is on a marginal walnut soil while the Martell soil is a fair to good walnut soil. Both sites have had fair to good weed control, annual pruning, and occasional fertilizer applications of Urea or 12-12-12.

Table 2.--Growth and form characteristics of patented Purdue 1 grafts vs. checks compared with Purdue 1 seedlings vs. checks.

	Height (ft.)	DBH (in.)	Volume (cu.ft.)	Stem Form[1]
9 years old -				
Purdue 1 grafts	26.6	4.9	1.77	1.3
Seedling checks	20.3	3.8	.92	3.3
Percent gain	31	29	92	61
11 years old -				
Purdue 1 seedlings	23.9	4.4	1.36	2.7
Seedling checks	21.5	3.7	.92	3.3
Percent gain	11	19	48	18

[1] Rating Scale: 1 = excellent form to
5 = very poor form.

Seedlings vs. the check do not show the percent gain of grafts vs. the check (table 2). This is an expression of several factors, including the graft's ability to exploit the full complement of inherited superiority as was discussed earlier. Another factor of great importance is that the seed collected from the superior tree in the natural setting includes an unknown male pollinator or several unknown pollinator components. They may have passed on superior genes or inferior genes for growth, etc. Therefore, the seedling mix contains a genetic component that is unknown and in all liklihood detrimental.

Form improvement is perhaps most indicative of the value of using clones. Stem form was obtained by subjectively rating the straightness of the main stem on a scale of 1 to 5 with 1 representing a perfectly straight stem, 2 - slight crook or deviation of the central stem, 3 - about average straightness, 4 - several severe crooks or a single fork, and 5 - a very crooked, forked and/or leaning central stem. In table 2, form improvement from seedling progeny is good, but improvement from clonal material is truly outstanding. It is significant to note that the check trees in both plantings had identical poorer than average stem forms, even though the two plantings are located 150 miles apart.

RISKS

The alleged problems associated with the planting of the same genotypes over large acreages, is often mentioned as a reason for not using clones (Zobel 1981). Monoculture invokes the specter of catastrophic losses to some unknown disease, insect or climatic happening. Dutch elm disease and chestnut blight are often used as examples. If a disease of this magnitude invades walnut, it will destroy them all whether they are of seedling or clonal origin. Monoculture was not the reason Dutch elm disease or chestnut blight spread so rapidly. Walnut is a native species well-adapted to the climate, diseases, and insects of the eastern U.S. Care must be taken to select only those clones that show some resistance or are not overly susceptible to the pests that affect black walnut. Of course, there is risk involved in using only a few clones but this must be balanced against potential gains in time, tree form, and nut production.

Black walnut growers are not the first long-term-tree crop orchardists to contemplate growing a few varieties over rather large acreage. For instance, fruit orchards usually contain a very limited number of clones (cultivars) that are usually not native to the area. The crop is long-term and there are few reports of catastrophic tree loss due to monoculture. A possible exception may be climatic losses due to varieties being planted outside of their hardiness zones. Fifty-year-old grafted pecan orchards are a closer comparison with black walnut and I'm sure that many NNGA members could point to similar examples of a few nut tree varieties planted in rather large blocks. In fact thousands of grafted Thomas black walnut trees have been planted in large blocks during the past 50 years with no reports of catastrophic disease or insect losses.

Even so, single clone monocultures are not recommended and mixtures of several clones and/or seedlings should be planted. Such mixes are probably more diverse genetically than most natural walnut stands when you consider that the various genetically improved clones and seedlings are from scattered geographic areas, while natural stands develop from local, often isolated, and related individuals (Beineke 1972).

Unique, often unexpected problems accompany any new endeavor and plantations of grafts rather than seedlings have their share. Most plantings of grafts have been made with containerized milk carton stock. The graft is usually only a few months old. The cartons are bulky and difficult to transport and plant. Also, root systems are reluctant to grow from the optimum rooting media of the container into the soil of the real world. Death or dieback of the graft often results during the winter months after outplanting. Unlike seedling dieback, which seldom results in any significant losses, graft dieback and resprouting of the root system means that the expensive and pampered graft has become a common seedling. This also occurs if the graft is damaged by animal predation, weed control tools, or wind. Winter dieback can be reduced by holding grafts over winter, and outplanting them as dormant bare-root grafts the following spring. This technique allows grafts to be handled and planted in the same manner as seedlings. Weed control, pruning, fertilization and other cultural treatments are the same for grafted plantations or seedling plantations.

CONCLUSIONS

Black walnut tree improvement has shown that rapid increases in growth and form can be made and in a few years grafts and seedlings from improved trees will be available in sufficient quantities to begin to meet the demand.

Seed orchards for genetically improved seedling production will still provide most of the black walnut seed required for regeneration purposes far into the future. As outlined in previous papers at this symposium, demand for walnut seedling stock is staggering. Due to the investment required and the unpredictability of propagation success, numbers of grafted trees will always be limited. Therefore, clonal propagation will probably remain a rather small percentage of total production. Grafted stock will be available for those growers who desire the maximum genetic improvement possible now and are willing to pay the high cost.

Despite cutbacks in research dollars and scientists involved in the genetic improvement of black walnut, prospects for future improvement appear optimistic. We have just begun to tap the tremendous genetic variation in growth, form, and nut-bearing capabilities in black walnut. New selections are presently under test that may prove to be far superior to anything now available. Studies have indicated methods that may allow us to select for superior growth rate at very early ages, perhaps one year, making it possible to avoid some of the long-term testing presently necessary. Selection, breeding and testing walnut for superiority must be a continuing process. Grafted plantations will prove to be a tool that will allow the landowner to take full advantage of rapid improvement.

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SOME GUIDELINES FOR SELECTING BLACK WALNUT PLANTING SITES

Felix Ponder, Jr.[1]

Abstract.--Black walnut grows best on fertile, deep, well-drained soils. Sites most often considered for growing walnut are abandoned farms that have never supported walnut. Therefore, soil information taken from other walnut sites must be used to evaluate the suitability of new areas for walnut.

Growing a crop of high-value walnut (Juglans nigra L.) trees is a long-term project that requires investments of land, time, and money. One of the black walnut grower's most important decisions is where to grow this valuable timber- and nut-producing hardwood. Successful walnut plantations are rare, mainly because many were established on unsuitable soils. But from successful plantations on suitable soils and from a few naturally established stands, we have learned much about where to plant black walnut. Frankly, a lot of what we know came from failures, also.

Broadly speaking, soil variables such as origin, physical condition, available water during the growing season, aeration, and nutrient availability determine how productive a site will be for black walnut or for any other vegetation. Losche and others (1972) developed a guide for selecting black walnut sites using these variables. As a result of their work, soils in Illinois were classified as suited, questionable, and unsuited for black walnut. However, the guide has been only partially successful, mainly because our knowledge is still too meager to measure accurately what determines the success of a walnut plantation. But the few variables we do know that contribute to good walnut growth have consistently shown to be reliable in determining plantation success.

Most soil site studies indicate that no single factor alone makes a site good, but that a combination of factors are involved. On the other hand, one single factor might make a site unsatisfactory for black walnut. Auten (1945) found that soil drainage, depth to mottling, and texture were the major factors determining site quality. A mottled zone is a layer that has spots or blotches of different colors or shades of colors; it is usually associated with water saturation. Losche (1973) concluded that an easily recognized soil characteristic "depth to gravel layer" can be used to rate the suitability of some floodplain soils for black walnut. More recently, Geyer and others (1980) showed that site quality for black walnut was closely related to soil and topographic characteristics. They found, in addition to those factors described by Auten and Losche, that soil origin, surface soil thickness, aspect, and water holding capacity were also important. These factors will be discussed here in detail.

LANDFORM

Site position and slope aspect are very important in site selection. Walnut grows best on deep, loose, alluvial soils, free of mottling. Carmean (1966) reported that on Sharon silt loam, a 25-year-old plantation had dominant trees 84 feet tall. Such exceptional growth exceeds all previously known growth records for black walnut.

Such bottomland sites are usually flat except for depressions of a few inches or, at most, a foot or two. Little depressions often indicate a tight, shallow soil that restricts water absorption. But this condition may be corrected by deep tillage and/or subsoiling.

Slope position and steepness as well as total soil depth often relate closely to surface soil thickness (Geyer and others 1980). Smooth and gently rolling landscapes generally present no critical problem. More important on these sites are soil characteristics such as texture and internal drainage. Shallow, heavy-textured, imperfectly drained upland soils are not suitable for walnut.

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The better planting areas on rolling and mountainous landscapes are usually located on the lower north- and east-facing slopes, stream terraces, and flood plains. These areas usually have the soil moisture and soil thickness required for satisfactory walnut growth. Steep, south-facing slopes and narrow ridge tops would generally be poor walnut sites. Such sites are often dry and because of their susceptibility to erosion are generally shallow. Depending on the geographic location, water deficiencies on south and southwest aspects may be intensified by high daytime temperatures and strong winds throughout the growing season. On soils having good soil moisture and more nutrients, organic matter tends to accumulate because of the more favorable conditions. But on dry and excessively drained soils, especially on hot sites, organic matter is quickly oxidized.

SOIL DEPTH

Black walnut tends to develop a large taproot which will penetrate 4 feet in 1 year and more than 9 feet in 3 years in well-drained, medium-textured soils. Because of walnut's deep rooting habit, Auten (1945) proposed that the surface soil in planting sites should be at least 16 inches thick and that soils having thinner surface soil should not be considered for walnut planting sites. However, I recommend that the minimum soil depth in a prospective site should not be less than 3 feet. Shallower soils will not hold enough water to support satisfactory growth. Also, the grower must realize that even the 3-foot depth could limit growth and the final product to be harvested. An effective soil depth of 5 feet (without restrictive layer) would better ensure good walnut growth.

TEXTURE

Soil texture influences the water holding capacity, available water, and the ease at which roots are able to penetrate. Black walnut generally prefers deep, well-drained silt loam soils. Suitable topsoil textures also include sandy loam and loam. The subsoil should have the same texture as the topsoil or a sandy clay loam or clay loam. Even though no consistent relationship has been found between pH and growth, soils with acid, clayey subsoils should be avoided. Good planting sites also include limestone soils with silt loam over clayey subsoils and deep rocky soils unsuitable for cultivation because of their rockiness. Usually walnut grows poorly on coarse-textured soils.

DRAINAGE

Walnut usually does not grow satisfactorily on poorly drained soils but it can tolerate occasional flooding of short duration. The site should be examined for evidence of restricted internal drainage which may affect surface drainage. Restrictive internal drainage causes poor aeration, leading to inhibited root growth and reduced tree height and diameter growth. Good internal drainage provides favorable conditions for the development of extensive root systems and more complete use of moisture and nutrients.

To estimate internal drainage, the grower must consider soil factors including texture, compaction, and structure. Color seems to be a good correlator of internal soil drainage and is the easiest to recognize. The color (mottling) of the subsoil is usually an indication of how much air (aeration) occupies the spaces between soil particles (table 1). Poor drainage due to heavy subsoil or a high water table is likely to produce a blue or drab color because the oxides of iron remain in the ferrous condition. If the soil has good internal drainage, the iron compounds are oxidized to red ferric oxides and the soil becomes red, brown, or yellowish-brown. Soils with evidence of mottling within 2 feet of the surface should be avoided.

Table 1.--Estimation of internal drainage based on soil color[1]

Drainage class	Color (mottling)	Possible topography
Very slow	Drab and blue below 8"	Swampy, high water table
Slow	Dull yellowish-brown below 14"	Low areas
Fair	Yellow 14-24"	Level upland
Moderate	Brownish-yellow below 35"	Rolling upland
Good-fast	Yellowish-brown	Terraces
Good-very fast	Red-brown	Moraines or loose sand

[1] Auten (1945) and USDA Soil Survey Manual (1962).

Both the gravel layer and mottling zone indicate soil conditions that inhibit deeper root growth. Therefore, soils with coarse sand or gravel layers and bedrock within 3 feet of the surface should be avoided.

OTHER FACTORS

Black walnut growing on bottomland sediments benefits from the greater water availability. Comparatively, upland soils, though well drained, usually lack the depth and organic matter which increase the amount of water a soil can hold.

Wind affects the establishment of black walnut. Seedlings planted in level, windswept, open fields are less vigorous, have smaller leaf areas, and suffer more foliage damage than those planted in similar soils in either forest openings or protected fields (Schneider and others 1970).

Vegetation on the site may indicate the fertility and/or moisture condition of the soil. A sparse cover of weeds and grasses generally indicates low fertility, erosion, or droughty soil conditions; such sites should not be planted to walnut. In contrast, a vigorous ground cover suggests the site may be suitable for planting walnut. Composition of the cover is also important. For example, sedges indicate a wet soil that probably is unsuitable for adequate walnut growth.

The soils of some old fields may contain toxic substances produced by other plants which could inhibit the nutrient uptake and growth of black walnut seedlings (see Rietveld paper presented at this symposium). Such toxic substances may also affect beneficial root-infecting fungi and microorganisms.

SITE IMPROVEMENT

Now comes the ultimate question: How can walnut be grown successfully on a parcel of land that lacks the proper drainage, depth, or other characteristics of an ideal walnut site? Several practices have been tried in an effort to increase the productivity of marginal sites. Most attempts such as fertilizing sites believed depleted of nutrients and refilling deep trenches and tile drainage in poorly drained soil have resulted in limited success. An alternative to fertilization may be interplanting with nitrogen-fixing plants such as autumn-olive or European alder. These plants can biologically fix atmospheric nitrogen which can later be released and used by other plants. Several studies have shown that planting autumn-olive with walnut increased site index by an average of 14 feet, changing what was originally considered a marginal site into a medium quality site for walnut. The effect of autumn-olive on growth was most dramatic on poor sites. However, care must be taken to prevent the spread of autumn-olive onto unwanted areas. Also encouraging are the early results from a forage legume study being done by researchers at Carbondale. Hairy vetch, which required 2 years for establishment, significantly increased seedling growth more than Korean lespedeza, crimson clover, and Sericea lespedeza did after 2 years of growth. Both hairy vetch and Sericea lespedeza controlled weeds better than the other legumes did (Van Sambeek and Rietveld 1981). Thus, planting companion trees and forage legumes on walnut sites may provide an alternative to chemical weed control and fertilization.

Cultural practices designed to increase available soil moisture might promote walnut growth. These practices include irrigation, terracing, mulching, and control of undesirable moisture using vegetation. Practices designed to improve subsoil drainage and aeration might include surface and tile drainage and, in addition, deep tillage may promote better rooting in the subsoil.

SUMMARY

To summarize, these are the major soil conditions to avoid in locating black walnut planting sites:

Problem	Indicators
Poorly drained	Compact subsoil; mottled 8-14"; sedges
Excessively dry site	Bedrock, coarse sand, and/or gravel layer <36" below the surface; compact subsoil; inadequate infiltration
Clay and silty clay	Compact subsoil; inadequate infiltration

Growers should look for sites having the following soil properties:

Soil properties	Indicators
Deep, well drained	Bottomland; >5' deep red-brown color
Limestone-derived soil	
Yellow, brown, or reddish brown subsoils	Without mottles and >3' deep

Knowing the relative productivity of soils in potential planting areas and existing walnut stands will enable the walnut grower to locate new plantations on the best available soils. Growers are urged to use state foresters, soil survey information, and research data in their search for suitable black walnut planting sites.

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THE SIGNIFICANCE OF ALLELOPATHY IN BLACK WALNUT CULTURAL SYSTEMS

W. J. Rietveld[1]

Abstract.--The importance of allelopathy in black walnut cultural systems was evaluated. Laboratory tests showed that 18 species being considered for mixed plantings with walnut were all sensitive to juglone. In mixed, even-aged plantations containing walnut, there is a buildup period of approximately 12-15 years before allelopathic effects become noticeable, if they occur at all. This allows ample time for growing short-term co-crops, nurse crops, and cover crops with walnut. Walnut's phytotoxic activity may even be beneficial in effecting its own release. Long-term mixed walnut/pine plantings are not recommended. The long-term allelopathic effects in mixed walnut/hardwood plantings are uncertain, and may be subtle. Potential allelopathic effects of plantation weeds on growth of walnut seedlings and saplings are considered, along with the need for vegetation management in plantations.

Through evolution, plant species have developed an array of intricate adaptations to ensure survival and perpetuation. One of these schemes--called allelopathy[2]--involves the production of chemical substances which, when released into the environment, directly or indirectly harms selected neighboring plants. Allelopathic chemicals may control the sequence and rate of plant succession, cause changes in species composition, and alter plant productivity. Allelopathy should not be confused with physical competition, because allelopathy involves a chemical compound being added to the environment, whereas competition involves the removal or reduction of some growth factor (light, water, nutrients, space) required simultaneously or sequentially by some other plant sharing the environment. The term "interference" refers to the overall deleterious effects of one plant on another, encompassing both competition and allelopathy (Muller 1969).

Black walnut (Juglans nigra L.) is the most notorious of allelopathic trees. However, that notoriety needs qualification. Most of the reported occurrences of walnut allelopathy (with the important exception of conifers) involves toxicity between existing large walnut trees and vegetables, field crops, fruits, and ornamentals. However, a subject that has not yet been addressed directly in the literature is: What are the implications of walnut allelopathy in forestry? As silviculturists, we are more interested in knowing the significance of allelopathy in forest and plantation situations. This paper will explore the documented and suspected allelopathic relationships that may occur in walnut plantations, assess their importance to walnut culture, and recommend silvicultural treatments to avoid or overcome their effects.

HISTORY OF BLACK WALNUT ALLELOPATHY

According to Gries (1943), the first written record of walnut toxicity can be traced back to the first century A.D., when Pliny the Elder, in his Naturalis Historia wrote: "the shadow of walnut trees is poison to all plants within its compass, and it kills whatever it touches."

Up to the present time, and especially during the past 50 years, walnut has been reported to be toxic to a wide variety of organisms including herbaceous and woody plants (Brooks 1951), fungi (Hedin et al. 1979), microorganisms (Krajci and Lynch 1978), insects (Gilbert et al. 1967), fish (Marking 1970), and mammals (Auyong et al. 1963). The principal chemical responsible for walnut allelopathy has been identified as juglone (5-hydroxy-1,4-naphthoquinone) (Davis 1928), which is found in the leaves, fruit hulls, inner bark, and roots of walnut (Lee and Campbell 1969). Rain washes it from living leaves and carries it to the soil; it is released also, along with tannins, from dead leaves and fruits to the soil. Juglone has been isolated from many plants in the walnut family, including black walnut, butternut (*J. cinerea* L.), Persian walnut (*J. regia* L.), Siebold walnut (*J. ailantifolia* Carr.), Manchurian walnut (*J. mandshurica* Maxim.), shagbark hickory (*Carya ovata* (Mill.) K. Koch), mockernut hickory (*C. tomentosa* Nutt.), Caucasian walnut (*Pterocarya fraxinifolia* (Lam.) Spach), and pecan (*C. illinoensis* (Wangenh.) K. Koch) (Thomson 1971, Graves *et al*. 1979).

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[2] Recent reviews on allelopathy include those by Sondheimer and Simeone (1970), National Academy of Sciences (1971), Whittaker and Feeney (1971), Rice (1974, 1979), Fisher (1976, 1979), Horsley (1976), and Rietveld (1979).

Not all reports have supported the existence of walnut toxicity, for in many cases species thought to be sensitive were observed co-existing with walnut. A controversy developed in which the key issue was whether root contact was necessary for toxicity to occur. The divergent results were best explained by Gries (1943) as follows:

> "Juglone, as such, occurs probably only in minute quantities in the inner root bark and in the green husks of the nuts. These regions, are, however, rich in a substance known as hydrojuglone. This compound, the colorless, non-toxic reduced form of juglone, is immediately oxidized to its toxic form upon exposure to the air or some oxidizing substance from the roots of other plants. Upon standing in the air, juglone again disappears, being either changed back to hydrojuglone or broken down into other non-toxic substances.... It now becomes possible for us to understand some of the discrepancies in the studies on walnut toxicity. If walnut bark or other plant parts are allowed to become desiccated, no toxicity may be found. If the roots of plants do not contact plant parts containing juglone or hydrojuglone, their oxidizing ability cannot produce the toxin."

Thus, the occurrence of toxic effects in sensitive species growing near a walnut tree depends on whether they are exposed to juglone as such. Juglone is a highly reactive substance and readily breaks down in well-aerated soil. Some plants may avoid exposure to juglone because their root systems are too shallow to contact the roots of walnut, while others may be capable of withstanding the strong oxidizing power of juglone.

PLANT ASSOCIATIONS INVOLVING BLACK WALNUT AND ALLELOPATHY

Four types of plant associations involving black walnut can be identified:

1. Natural forest stands containing walnut as a component.
2. Various species planted within the influence zone of existing large walnut trees.
3. Sapling plantations containing an even-aged mixture of walnut and one or more other woody species.
4. Walnut seedlings planted admidst herbaceous vegetation.

The first two types of plant associations are listed for completeness, but they are not the subject of this paper and will be mentioned only briefly.

A comprehensive survey of the association of native vegetation with black walnut trees was published by Brooks in 1951. His extensive tables list over 218 species growing within and outside the root and crown spreads of walnut trees. While some species (e.g., blackberry, blueberry, heaths, pines) are rarely associated with walnut, others (Kentucky bluegrass, black raspberry) grow better within the root zone of walnut than outside. The potential roles of allelopathy in differentiation, patterning, and composition of natural forest stands were discussed in a previous paper by the author (Rietveld 1979).

The majority of existing literature on occurrence of walnut allelopathy involves the second type of plant association. These numerous reports of toxicity between existing walnut trees and vegetables, field crops, fruits, and ornamentals are largely responsible for walnut's reputation as an allelopath. The literature on these associations was reviewed by Brooks (1951) and more recently by MacDaniels and Pinnow (1976).

The latter two plant associations involving black walnut in plantations are the subject of this paper and are discussed at length in the following sections.

ALLELOPATHIC POTENTIAL OF BLACK WALNUT ON PLANTATION VEGETATION

Recent research has shown that mixed plantings of certain nitrogen-fixing species with black walnut in plantations can substantially boost growth, and possibly quality (Funk et al. 1979a, Van Sambeek and Rietveld 1981). Other species are being considered as possible co-crops with walnut to diversify vegetation and increase overall product yields. However, we know nothing about the sensitivity of these species to juglone.

The experiments reported here were conducted to assess the allelopathic potential of black walnut juglone to several herbaceous and woody species which are being considered for co-crops, nurse crops, and cover crops in intensively cultured black walnut plantations.

Effects of Juglone of the Growth of Coniferous Seedlings

In an earlier experiment reported elsewhere (Funk et al. 1979b), seedling growth of four conifer species was tested in the laboratory for sensitivity to juglone. Seedlings of Japanese larch (Larix leptolepis (Sieb. and Zucc.)), Norway spruce (Picea abies (L.) Karst.), eastern white pine (Pinus strobus L.), and Scotch pine (P. sylvestris L.) were established in a hydroponic system installed in a growth chamber. The seedlings were grown for 8 to 10 weeks in a nutrient-plus-juglone solution at juglone concentrations ranging from 10^{-2} Molar (M) to 10^{-10} M.[3]

At concentrations at 10^{-2} M and 10^{-3} M, juglone was lethal to all species; Scotch pine and Japanese larch seedlings were killed at a concentration of 10^{-4} M. Juglone caused no visible injury to white pine at concentrations of 10^{-6} M and less, and 10^{-5} M and less for the other species, but seedling growth was inhibited by solutions as dilute as 10^{-7} M.

All of the conifers tested were quite sensitive to juglone and death resulted when the juglone concentration exceeded 10^{-4} M. Short-term exposure to intermediate concentrations resulted in measurable reductions in plant dry weight without the appearance of toxicity symptoms. However, the effects of long-term exposures to low and moderate juglone concentrations in the field are unknown.

Effects of Juglone on Seed Germination and Seedling Growth of Several Herbaceous and Woody Species

The following recently-completed experiment tested the effect of juglone on several plant growth processes in a variety of species. The experiment consisted of two parts: (1) seed germination and radicle elongation in various juglone concentrations, and (2) shoot elongation and dry weight accumulation in hydroponic cultures containing the same juglone concentrations.

Materials and Methods

The following species were tested:

Herbaceous legumes:

- Crimson clover (Trifolium incarnatum L.)
- Crown vetch (Coronilla varia L.)
- Hairy vetch (Vicia villosa Roth.)
- Korean lespedeza (Lespedeza stipulacea Maxim.)
- Sericea lespedeza (Lespedeza cuneata (Dumont) G. Don)

Shrubs:

- Ginnala maple (Acer ginnala Maxim.)
- Siberian peashrub (Caragana arborescens Lam.)
- Russian olive (Elaeagnus angustifolia L.)
- Autumn olive (Elaeagnus umbellata Thunb.)
- Amur honeysuckle (Lonicera maackii Maxim.)

Trees:

- White oak (Quercus alba L.)
- White ash (Fraxinus americana L.)
- Yellow poplar (Liriodendron tulipifera L.)
- European black alder (Alnus glutinosa (L.) Gaertn.)
- Eastern white pine (Pinus strobus L.)
- Scotch pine (Pinus sylvestris L.)

Certain species were not included in both tests because of problems in obtaining, stratifying, or germinating seed. Seed was collected and stored until needed. Germination tests were run in a laboratory germinator using standard recommended pregermination treatments, test conditions, and germination criteria (Association of Official Seed Analysts 1970, International Seed Testing Association 1976, USDA Forest Service 1974). Four trays of 100 seeds each were germinated in each of four juglone concentrations: 10^{-6} M, 10^{-5} M, 10^{-4} M, and 10^{-3} M, plus a control (0 concentration). Identical tests were run on two media, blotter paper and soil.

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[3] Equivalent percentage concentrations ranged from 0.2 to 0.000000002 percent, respectively.

When germination was occurring at a rapid rate, 10 germinants were retained on each tray for measurement of radicle elongation. Radicle length was measured initially and again after 10-15 millimeters of elongation had occurred in the controls, usually 2-6 days.

In the second part of the experiment, seedlings were grown in hydroponic culture to test the effects of juglone on shoot elongation and dry weight accumulation. Seedlings were grown in sand to the first true leaf stage, then transferred to nutrient solution containing the same juglone concentrations used in the germination tests. The apparatus was the same unit described in the conifer growth experiment. Solutions were changed weekly. Tests ran 4-6 weeks, depending on rates of growth and symptom development. Seedling height was measured initially and repeatedly during the tests. At the end of each test, seedlings were harvested and plant dry weight determined.

Results

Seed germination.--Only the results using forest soil as the germination medium are reported, since the results using the blotter medium were similar. Percent germination was significantly affected by juglone in only three of the 14 species tested: sericea lespedeza was inhibited by the 10^{-6} M and 10^{-3} M concentrations, and white oak and amur honeysuckle germination were stimulated by the 10^{-6} M concentration (fig. 1A).

Radicle elongation.--Radicle elongation was more sensitive to juglone than was seed germination, with six of the 14 species tested significantly affected (fig. 1B). The pattern of response varied by species, but the 10^{-3} M concentration caused the most consistent and marked reduction in elongation. Radicle elongation of amur honeysuckle and black alder was stimulated by the 10^{-6} M and 10^{-5} M concentrations, respectively.

Shoot elongation.--All species were killed by 10^{-3} M, and severely inhibited by 10^{-4} M juglone. Five species (crimson clover, sericea lespedeza, amur honeysuckle, white ash, and black alder) were significantly inhibited by the 10^{-5} M concentration, and amur honeysuckle seedlings were also inhibited by 10^{-6} M juglone (Fig. 2A). Only severely inhibited seedlings (10^{-3} M, 10^{-4} M) showed visible symptoms (chlorosis) of juglone toxicity. Crown vetch was omitted because of its tendency to form a basal crown rather than elongate.

Plant dry weight.--Juglone effects on plant dry weight accumulation were greater and more distinct than on shoot elongation. Dry weight of white oak seedlings was not significantly affected by juglone. In the remaining species, however, concentrations of 10^{-5} M and greater significantly inhibited dry weight accumulation in all species except ginnala maple, Russian olive, and yellow-poplar (fig. 2B). Plant dry weight accumulation was also significantly inhibited by 10^{-6} M juglone in sericea lespedeza and autumn olive. In three species (Siberian peashrub, Russian olive, and yellow-poplar), dry weight of seedlings grown in 10^{-6} M and 10^{-5} M juglone was higher than in the control, but not significantly so. These responses are attributed to exceptional growth of a few individual seedlings. More vigorous seedlings are apparently more resistant to juglone.

Discussion

Every species tested was found to be sensitive to juglone. All species were killed by 10^{-3} M juglone, and in most species many seedlings were killed by 10^{-4} M juglone. The species varied independently in the growth processes affected and in their degree of sensitivity. Of the species included in all of the tests, the five most sensitive to juglone were sericea lespedeza, amur honeysuckle, hairy vetch, ginnala maple, and autumn olive; the least sensitive species were white oak and Russian olive.

Data from these short-term tests are useful for comparing species sensitivity to juglone and the relative sensitivity of different growth processes. However, biological assays are insufficient as a means of identifying the occurrence of allelopathy and the concentrations of chemicals responsible for allelopathy in the field (Stowe 1979). It is unlikely that 10^{-3} M juglone occurs under field conditions because it is difficult to prepare in the laboratory, and some juglone usually precipitated out in hydroponic culture. More likely, the allelopathic effects observed in the field are the result of longer-term exposures to low and moderate juglone concentrations under soil conditions which favor juglone persistence and increase plant susceptibility. The juglone toxicity experiments also suggest that low juglone concentrations may inhibit (or stimulate) growth for a period of time before any toxicity symptoms appear.

Significance of Black Walnut Alleopathy in Plantations

Although every species tested was found to be sensitive to juglone under short-term

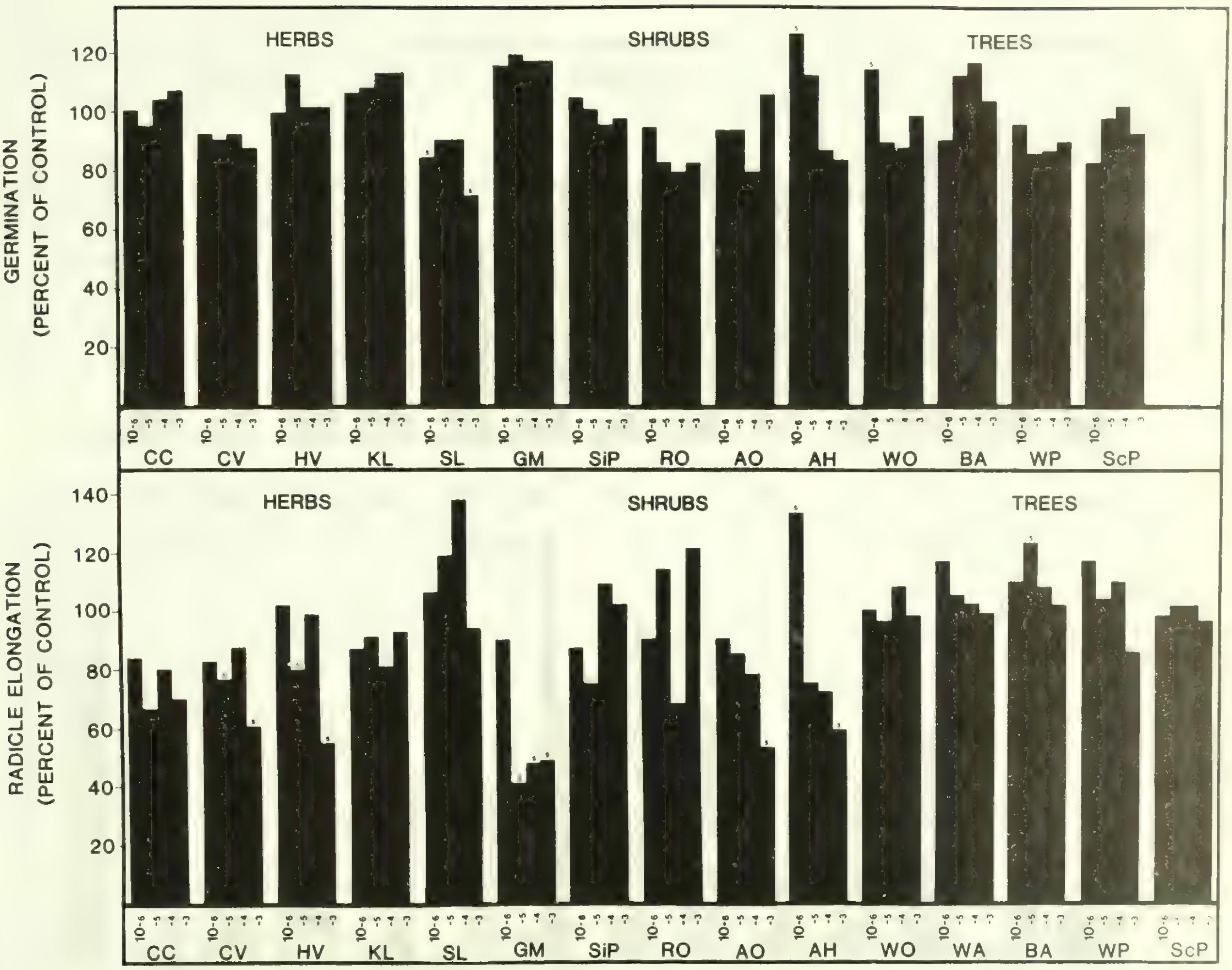

Figure 1.--Effects of juglone on: (A) seed germination and (B) radicle elongation of germinated seed of several herbaceous, shrub, and tree species. Responses to the four juglone concentrations are given as a percentage of the control (0 concentration). Species abbreviations: CC = crimson clover, CV = crown vetch, HV = hairy vetch, KL = Korean lespedeza, SL = sericea lespedeza, GM = ginnala maple, SiP = Siberian peashrub, RO = Russian olive, AO = autumn olive, AH = amur honeysuckle, WO = white oak, WA = white ash, YP = yellow-poplar, BA = black alder, WP = eastern white pine, ScP = Scotch pine. Each value is the mean of four trays of 100 seeds on forest soil.

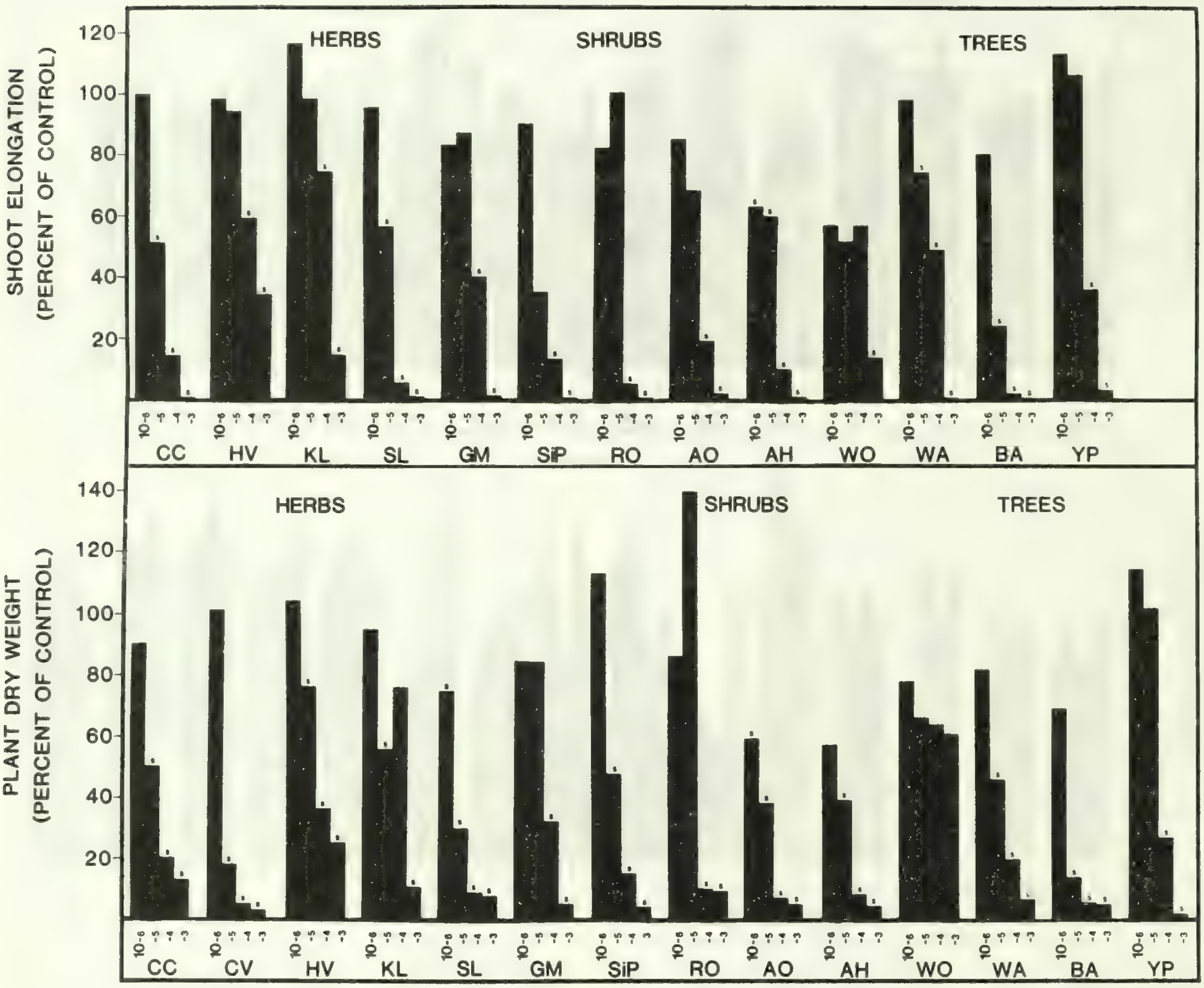

Figure 2.--(A) Seedling shoot elongation and (B) plant dry weight of several herbaceous, shrub, and tree species grown for 4-6 weeks in aerated nutrient solutions containing juglone. Growth responses to the four juglone concentrations are given as a percentage of the control (0 concentration). Species abbreviations are the same as in figure 1. Each bar is the mean of 12 seedlings.

laboratory conditions, the occurrence of allelopathy under field conditions depends on several important factors: (1) size and density of the walnut trees; (2) the sensitivity of associated species to juglone; (3) soil conditions which control the disposition of juglone, and (4) management objectives--the intended purpose and duration of co-planted species.

Information on several mixed, even-aged walnut plantations obtained from the literature and gathered through personal contacts is summarized in table 1. Although specific information on the compatibility of walnut with other species and the factors that affect it is not available, some general observations from the table and speculations will be discussed in the following sections.

The Buildup Period

There is a distinct difference between allelopathy resulting from planting species near existing large walnut trees and allelopathy in mixed, even-aged plantations containing walnut. In the former case, toxicity may occur within months or a few years, while in the latter case there is a buildup period--the time required for walnut trees to grow to sufficient size and density to have a significant chemical effect on the environment. Knowledge of the relative length of the buildup period and of factors that affect it are useful for silviculturalists wanting to grow short-term crops of other species with walnut.

A buildup period of approximately 12-25 years is needed for planted walnuts to reach a sufficient size and density to produce and release enough juglone to result in noticeable allelopathic effects (table 1). It is unknown when and for how long toxicity occurred before symptoms appeared, since moderate juglone concentrations may inhibit growth without visible injury. On the other hand, allelopathy may not occur at all, even in sensitive species, if they are growing vigorously on well-drained sites.

Species Sensitivity

There is no doubt that species vary in their sensitivity to black walnut juglone, as evidenced by Brooks' extensive surveys (Brooks 1951), the juglone toxicity experiments reported here, and table 1. Of the plantations summarized in table 1, walnut/pine mixtures were the most frequent and showed the most consistent occurrence of allelopathy. Pines are commonly planted and are especially sensitive to juglone. Although data are scarce for species other than pines, conifers as a group appear to be more sensitive to juglone than deciduous species.

European black alder has received increasing interest as a nurse crop species with black walnut in plantations. It is interesting to note in table 1 that allelopathy occurred in three out of seven mixed walnut/black alder plantations. With close spacing, the alders started dying in as little as 7-8 years. In the juglone toxicity experiments reported in this paper, black alder was one of the most sensitive species tested (figs. 1 and 2). However, autumn olive, a recommended nurse crop species (Funk et al. 1979a), was nearly as sensitive to juglone (figs. 1 and 2) but has not yet shown any noticeable allelopathic effects in the field (table 1).

Soil Factors

The principal factor affecting the length of the buildup period appears to be soil conditions, specifically soil moisture and soil aeration. Fisher (1978) found a strong relationship between soil moisture and the allelopathic activity of walnut trees. As soil moisture increased from dry to wet, the amount of extractable juglone and allelopathic activity increased. High soil moisture creates anaerobic reducing conditions that are unfavorable for the chemical and biological oxidation of juglone. Although there is no direct evidence of microbial breakdown of juglone, it seems most probable that it occurs (Fisher 1978). Soil conditions also influence growth rates and vigor, which in turn determine tree size and juglone production by walnut, and are related to susceptibility of associated species to juglone toxicity.

The relation between soil drainage (and interrelated soil factors) and the occurrence of allelopathy is evident in table 1. Eastern white pine planted on well-drained, coarse-textured soils in Wisconsin, Ontario, and Michigan are growing well with walnut after 15, 20, and 44 years, while the same species growing on moderately-drained, finer-textured soils elsewhere were killed in as little as 13 years. On some well-drained sites in Ontario, white pine has actually shaded out the walnut over a period of 20 years (personal communication with Dr. Richard F. Fisher). This implies that walnut interference to the growth of other species is due both to competitive and allelopathic factors, and the effectiveness of the latter factor is controlled by soil conditions.

Table 1. Summary of available data on compatibility of various species with black walnut in mixed, even-aged plantations. The age and size of walnut trees are those when toxicity was first noted, or current data where no toxicity has occurred

State	Associated species	Black walnut trees		Soil drainage class2/	Condition associated species	Source
		Age (years)	Diameter1/ (inches)			
Illinois	Red pine	24		well	Dead and dying	Mr. Howard Fox (retired)
	White pine	24		well	Dead and dying	Sinnissippi Forest
	Red pine	16		well	Yellowing	Oregon, IL
Ontario	White pine	35			Dead and dying	Fayle (1976)
	White pine	4			Growing well	
Ontario	White pine + Red pine	30		well	Growing well	Fisher (1978)
	White pine + Red pine	20		moderate	Poor survival and growth	
	White pine + Red pine	20		poorly	Dead	
Ontario	Red pine + N. red oak	21		moderate	Dead and dying Growing well	von Althen (1968)
Indiana	White pine	23	8.4	moderate	Yellowing and declining	Dr. Clair Merritt
	White pine	17	2.5	moderate	Growing well3/	Dept. Forestry and Natural
	Yellow-poplar + Red oak	19	6.3 1.2	moderate	Growing well3/ Growing well	Resources Purdue University
	Jack pine	16	5.1	moderate	Growing well	W. Lafayette, IN
Indiana	White pine	13	4.2	moderate	Dead and dying	Mr. Robert D. Burke
	White pine	13	3.6	well	Yellowing	Pierson-Hollowell Co.
	Black alder	12	7.0	moderate	Dead and dying	Martinsville, IN
	Autumn olive	14	5.5	moderate	Growing well	
	Autumn olive	14	4.4	moderate	Growing well	
	Autumn olive	14	4.8	moderate	Growing well	
Missouri	Black alder	8	2.9	well	Dead and dying	Dr. Richard C. Schlesinger
	Autumn olive	11	4.6		Growing well	Dr. Felix Ponder, Jr.
Illinois	Black alder	11	1.8		Growing well	North Cent. For. Exp. Stn.
	Autumn olive	11	4.2		Growing well	Carbondale, IL
	Black alder	11	3.0		Growing well	
	Autumn olive	11	4.9		Growing well	
	Black alder	7	2.7		Dead and dying	
	Autumn olive	11	6.1		Growing well	
	Black alder	15	6.0		Growing well	
	Black alder	14	3.1		Growing well	
Wisconsin	White pine	15	4.8	well	Growing well	Mr. Ken Ellis, Brooklyn, WI
Michigan	White pine	44	10.0	well	Growing well	Mr. Walter Lemmien
	White pine	35	9.0	well	Pines close to BW dead	Michigan State University East Lansing, MI
	Red pine	44	12.0	well	Growing well	
	Honey locust	40	7.0	well	Growing well	
	White oak	39	7.0	well	Growing well	
Iowa	Silver maple	16	4.0	moderate	Dying back and dead	Mr. John L. McSweeny Iowa State Conservation Comm.
	Red pine	8	2.5	moderate	Yellowing and declining	McGregor, IA
	Red pine	24	5.0	moderate	Dead and dying	
	White pine	13	3.0	moderate	Growing well	
Kansas	Black locust	31	7.0	well	Growing well3/	Mr. Nelson Rogers (retired)
	Bur oak + Green ash + E. red cedar + Sycamore	32	7.0	well	Growing well	North Cent. For. Exp. Stn. Salem, MO
Iowa	White ash	12	4.0	moderate	Growing well	Mr. Ed Gardiner Iowa State Conservation Comm. Anamosa, IA
Kansas	Ash + hackberry	11		--	Growing well	Mr. Gary G. Naughton Kansas State University Manhattan, KS
North Carolina	Black alder	10	6.5	well	Possibly declining	Mr. Dwight L. Brenneman North Carolina Forest Service Morganton, NC
Indiana	White pine + Japanese larch + Red oak + Red gum	12	--	well	Growing well	Mr. Richard Rambo
Missouri	Scotch pine + Blue spruce	12	3.5	moderate	Growing well	Mr. John P. Slusher University of Missouri Columbia, MO

1/ Diameter at breast height, 4.5 feet above the ground.

2/ Soil drainage class gives an indication of soil texture and organic matter content, and is related to the degree of aeration and moisture availability. Classes used are well-drained (well), moderately drained (moderate), and poorly drained (poor).

3/ Most black walnut trees shaded out.

Management Objectives

The importance of black walnut allelopathy is greatly influenced by the silvicultural goals and the duration of the species co-planted with black walnut. Allelopathy does not appear to be a problem for growing short-term crops of various herbaceous and woody species with black walnut in plantations. Such short-term crops should be either harvested or expendable after 15 years. Even sensitive species can be considered for nurse crops or co-crops, if the benefits are worth the investment.

Pines can be given serious consideration as a short-term nurse crop for black walnut on well-drained sites. Pines produce dense side shade needed to encourage height growth and good form in the walnuts, provide wind protection (especially in winter months), and help shade out plantation weeds. If their shape and color are good, some of the pines can be harvested after 7-10 years and marketed as Christmas trees, permitting recovery of plantation establishment costs and thus increasing returns on the investment in walnut.

When nurse crops are grown with walnut, the phytotoxic activity of walnut may prove to be a benefit by providing release from overcrowding.

The potential of allelopathy in long-term mixed plantings with walnut is more uncertain. Long-term mixed walnut/pine plantings are not recommended because it is too uncertain whether the pines will survive to maturity. The compatibility between black walnut and other hardwood species is unclear. While on the one hand several tree species (white ash, yellow-poplar, black alder) were found to be sensitive to juglone in the experiments reported here, walnut is commonly found associated with these and many other important forest tree species of the eastern hardwood region (Brinkman 1957). If allelopathy is involved, then it is reasonable to suggest that the influences are a matter of degree--i.e., relative effects on the abundance, vigor, and growth of other species. This may help explain why black walnut, a rather poor competitor, is able to exist in mature forest stands. Apparently, the species and individuals present are those that have successfully (at least for the present) adapted to accommodate each other. The unsuccessful species and individuals have disappeared inconspicuously over a period of time.

The situation in mixed, even-aged plantations may be different. Walnut is usually planted at higher density and/or favored in thinnings because it is a preferred species. Many changes will eventually occur in these artificially created stands, both competitively and allelopathically induced, that will result in the less competitive, intolerant, and juglone-sensitive species and individuals being eliminated. These changes are likely to be more abrupt and noticeable. Although juglone sensitivity of most eastern hardwood species appears to be less than that of conifers, the potential for allelopathy in mixed plantations is greater than in natural stands.

ALLELOPATHIC EFFECTS OF PLANTATION VEGETATION ON BLACK WALNUT

Black walnut plantations are commonly established on ex-agricultural land and old fields. The vegetation consists of: (1) black walnut and nurse crop (if any) seedlings, and (2) a diversity of volunteer herbaceous vegetation. The herbaceous component is by far the most abundant; thus, young tree plantations are essentially old fields for several years. Herbaceous plant succession occurs fairly rapidly, following a general pattern of broad-leaved weeds giving way to annual grasses, then to perennial grasses (Rice 1974). Recent research has shown that allelopathy is an important factor causing plant succession in old fields (Rice 1974, 1979).

Many of the same genera shown by Rice's group to be allelopathic to associated vegetation and microorganisms have been reported by other investigators to interfere with tree seedlings (table 2). Because of a lack of research, there are no specific reports of herbaceous vegetation allelopathically inhibiting the growth of black walnut seedlings. The implications are: (1) there is an increasing number of reports of certain herbaceous species releasing substances inhibitory to tree seedlings; (2) many of these herbaceous species are abundant in black walnut plantations; (3) thus, the potential for interference with black walnut seedling growth is great.

Weed control is a necessary and highly recommended practice for establishing black walnut plantations (Schlesinger and Funk 1977), for without it seedlings are typically suppressed for many years. Recent evidence suggests that more is accomplished by weed control than controlling competition; allelopathic interactions may also be controlled without knowing they exist. Weeds around individual seedlings should be controlled for 2-3 years after transplanting to allow the tree seedlings to become established. After weed control is curtailed, the surrounding herbaceous vegetation closes back in, and the trees are susceptible to interference from herbaceous vegetation until

Table 2.--Summary of literature on allelopathic effects of herbaceous vegetation on tree seedlings

Producing species	Receiving species	References
Bracken fern Wild oak grass Wrinkled goldenrod Flat-topped aster Hay-scented fern New York fern Short husk grass Club moss	Black cherry	Horsley, 1977a, 1977b
Broomsedge	Loblolly pine	Priester and Pennington 1978
Aster Goldenrod	Yellow-poplar Virginia pine	Haney 1969
Ragweed New England aster Daisy fleabane Hawkweed Timothy Tall buttercup Canada goldenrod Grass-leaved goldenrod	Sugar maple	Fisher *et al*. 1978
Orange hawkweed	Balsam fir White pine	Dawes and Maravolo 1973
Mountain muhly Arizona fescue	Ponderosa pine	Rietveld 1975
Tall fescue	Sweetgum	Walters and Gilmore 1976
Giant foxtail	Loblolly pine	Gilmore 1980
Tall fescue	Loblolly pine	Wheeler and Young 1979
Tall goldenrod Broomsedge Crownvetch Wild carrot Tall fescue Timothy	Black locust	Larson and Schwarz 1980

they attain sufficient size to be unaffected. That period may extend for 10 years or more.

Of the herbaceous species listed in table 2, those considered to have the greatest allelopathic potential to inhibit growth of black walnut seedlings are asters, goldenrods, fescue, and broomsedge. There is a growing body of evidence on the allelopathic activity and competitiveness of tall fescue (*Festuca arundinacea* Schreb.). Besides the reports summarized in table 2, fescue has also been reported to be toxic to the legumes birdsfoot trefoil (*Lotus corniculatus* L.) (Peters 1968) and Ladino clover (*Trifolium repens* L. cv. Tillman). Fescue is common in established walnut plantations. When heavy fescue sod in part of a 9-year-old pure walnut plantation was rotovated in June 1980, a noticeable growth response occurred the same season. With exceptionally good rainfall early the following summer, the released walnuts greatly expanded their foliage and were dark green, compared with unreleased trees which grew only modestly and were light green in color (personal communication with Dr. Richard C. Schlesinger).

Besides possible allelopathic effects, fescue is especially competitive to black walnut seedlings and saplings. Todhunter and Beineke (1979) reported that tall fescue is acutely competitive with walnut seedlings for soil water, phosphorus, and potassium. They suggested that fescue's competitiveness is due to its dense and deep rooting habit and heavy infection of vesicular-arbuscular mycorrhizae. Holt and Voeller (1975) found that removing fescue cover increased diameter growth and nut yield of 10- to 12-year old walnut trees. This evidence justifies the recommendation that fescue not be used as a cover crop in black walnut plantations.

Allelopathic chemicals from herbaceous vegetation may also inhibit certain microorganisms essential to the growth of tree seedlings. Persidsky et al. (1965) found that water extracts of prairie soils significantly inhibited oxygen uptake by mycorrhizal short roots of Monterey pine (Pinus radiata D. Don.) and red pine (P. resinosa Ait.), compared with extracts of forest soils. Theodorou and Bowen (1971) found that decomposition products of grass roots reduced the number of infections of an ectotrophic mycorrhizal fungus on Monterey pine. Rice (1972) found that broomsedge inhibits Azotobacter and Rhizobium, two important nitrogen-fixing bacteria. Since broomsedge is known to compete vigorously and grow well on soils of low fertility, he suggested that inhibition of nitrogen-fixing and nitrifying bacteria would keep the nitrogen supply low and give broomsedge a selective advantage over species that have higher nitrogen requirements.

Soil conditioning is needed on sites that have been dominated by herbaceous vegetation for a number of years. In the forest-prairie ecotone of north-central Oklahoma, Petranka and McPherson (1979) found that bottomland forest trees were unable to invade climax tallgrass prairie without the prior invasion of sumac (Rhus copallina L.) and other shrubs. Upland forest trees were able to invade climax prairie, but the invasion was enhanced by the prior invasion of shrubs. Carmean et al. (1976) found that growth of planted hardwood seedlings was strikingly better on areas that had recently supported some kind of tree cover, versus areas dominated by herbaceous cover. They attributed the differences to several physical, biological, and chemical soil factors, including allelopathy.

An alternative method to achieve both weed control and soil conditioning is to establish companion crops in plantations, i.e., woody nurse crops and herbaceous cover crops that are compatible and soil-building. Ideally, the species selected (e.g., pines, successional woody species, exotics, and leguminous cover crops) should tolerate allelopathic chemicals in the soil. They should quickly develop into dense stands which exclude weeds (possibly allelopathically), enrich the soil through nitrogen fixation and/or addition of organic matter, create a favorable microclimate, and minimally compete with the planted trees.

Our initial research on establishing herbaceous, nitrogen-fixing cover crops in black walnut plantations has been successful (Van Sambeek and Rietveld 1981). Hairy vetch has been especially promising because it effectively suppressed weeds and stimulated walnut seedling growth. However, it overtopped and deformed some of the shorter walnut seedlings. Korean lespedeza was not effective in suppressing the tall summer weeds. Crimson clover with Korean lespedeza suppressed the tall summer weeds, but not the warm season grasses, especially giant foxtail (Setaria faberii Lamb.). Sericea lespedeza and crownvetch were slow to establish, but suppressed weeds beginning the second year. Their effects on seedling growth remain to be determined.

Another potentially important role of certain companion crops is their ability to colonize soil microorganisms essential for tree growth. Kormanik et al. (1980) found that seeding corn, millet, sudex, and sorghum as nursery cover crops increased inoculum density of vesicular-arbuscular fungi (Glomus spp.) in nursery soils. These are the same fungi that form entotrophic mycorrhizal associations with black walnut roots, which are considered to be important for tree growth. Companion crops that colonize essential microorganisms in the soil need to be tested in plantations to determine the potential benefits to transplanted black walnut seedlings.

Vegetation Management

The planting of nurse crops and cover crops in plantations, orchards, etc. is not a new concept in agriculture and forestry. The obvious benefits of weed suppression and nitrogen-fixation have long been known. But companion crops have not been utilized for years because inexpensive and more conventional chemical fertilizers and pesticides were available to do the job.

Recent escalation of costs of materials and labor, and environmental concerns, have necessitated a renewed interest in companion planting. However, besides renewed interest there is increased awareness. It is becoming increasingly clear that plantation weeds do more than compete with tree seedlings. Our increasing knowledge of plant/plant and plant/microorganism allelopathy has made us aware that besides direct inhibition of plant growth there may be indirect effects on growth through inhibition of beneficial and essential soil microorganisms. The term "interference" appropriately describes the situation, because it encompasses the overall deleterious effects of both competition and allelopathy in interplant relationships (Muller 1969).

While weed control with chemical herbicides may eliminate interference, companion plantings of appropriate species have the additional potential to condition and enrich the soil physically, chemically, and biologically to make it more favorable for tree growth. The modern version of companion planting in black walnut cultural systems is vegetation management. The concept of vegetation management in plantation establishment recognizes that there will be vegetation present that competes with the trees. However, rather than dealing with volunteer successional vegetation (by repeated herbicide spraying and mowing), selected compatible herbaceous and woody species are co-established with the tree seedlings. The companion species should be non-allelopathic (to walnut), minimally competitive, and should suppress weeds and enrich the soil. The overall potential benefits are soil conditioning and enrichment, elimination of allelopaths, reduction of competition, reduction of disease and insect damage, growth stimulation, and improvement of tree quality. Our continuing research will determine the extent of benefits and cost effectiveness of plantation vegetation management and will provide this information to landowners and managers.

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

The principal points made in the paper are summarized as follows:

1. There is a great deal of literature on the toxic effects of black walnut that creates the false impression that few species can be planted with walnut. Most of these reports involve toxicity to vegetables, field crops, fruits, and ornamentals, which are of lesser interest to foresters. This paper evaluates the importance of walnut allelopathy in forestry.

2. Four types of plant associations involving black walnut and allelopathy were identified: (a) natural forest stands containing walnut as a component, (b) various species planted within the influence zone of existing large walnut trees, (c) mixed, even-aged sapling plantations containing walnut, and (d) transplanted walnut seedlings establishing admidst herbaceous vegetation. The latter two plant associations are the subject of this paper.

3. Laboratory tests of juglone sensitivity of 18 species being considered for mixed plantings with walnut showed that all were sensitive to juglone. Seed germination and radicle elongation were inhibited mainly by high juglone concentrations, which were unlikely to occur in nature. However, shoot elongation and dry weight accumulation were sensitive to juglone concentrations as low as 10^{-7} M. Symptom development and death occurred only at very high concentrations (10^{-4} M and 10^{-3} M). Conditions which result in allelopathic effects in the field are unknown, but are likely to be a combination of longer-term exposures to moderate juglone concentrations combined with soil conditions that favor juglone persistence and increased plant susceptibility.

4. When walnut and other species are established together in plantations, there is a buildup period of approximately 12-25 years before allelopathic effects become evident, if they occur at all. The length of the buildup period depends on the age and density of walnut trees, juglone sensitivity and vigor of associated species, and soil conditions. Allelopathy is more likely to occur on imperfectly drained soils where chemical and microbial oxidation of juglone is restricted.

5. The importance of walnut allelopathy depends on silvicultural objectives: where the intention is to grow crops with walnut beyond 12-25 years, the tree grower should be cognizant of possible allelopathic effects; but where walnut is grown as the only eventual crop, there is little reason to be concerned about allelopathy. Moreover, walnut's selective toxic effects may be beneficial for bringing about its own release. Allelopathy does not appear to be a factor discouraging the planting of nurse crops, even pines, during the early part of the rotation.

6. There is a growing body of evidence which suggests that interference from plantation weeds may inhibit growth of tree seedlings during the establishment phase. It is quite possible that walnut will joint the list of species affected. It is already known that plantation grasses, especially fescue, are severely competitive to walnut. Fescue is not recommended as a cover crop in walnut plantations.

7. Besides eliminating competition, controlling weeds may also avoid allelopathic influences for the first 2-3 years after planting. After weed control is curtailed, herbaceous vegetation re-establishes, and the extent of allelopathic activity is unknown. Recent research on woody nurse crops and herbaceous cover crops in plantations has shown that these associations smother weeds and stimulate tree growth.

8. The concept of vegetation management involves co-establishing compatible and beneficial companion species with tree seedlings in plantations. The potential benefits are soil conditioning and enrichment, elimination of allelopaths, reduction of competition, reduction of insect and disease damage, growth stimulation, and improvement of tree quality.

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PRUNING FOR QUALITY

Richard C. Schlesinger[1]

Abstract.--Artificial pruning can improve tree quality but can reduce growth and quality if incorrectly done. Pruning causes wounds and pruning of live branches may reduce growth. Corrective pruning is not generally useful for the development of high-quality plantations. But lateral pruning is needed and should be done in stages beginning when the trees are small. By understanding tree responses to pruning, we can improve tree quality and plantation value through proper pruning practices.

Black walnut (*Juglans nigra* L.) veneer logs generally command prices 8 to 9 times higher than saw logs. But without some artificial pruning, few black walnut trees develop the straight, clear boles needed for veneer unless we are willing to extend the growing period beyond 80 to 100 years. Although artificial pruning can improve tree quality, it can also reduce growth and quality if carelessly or incorrectly done. By understanding tree response to pruning, the grower can determine how best to prune an individual tree.

TREE GROWTH AND RESPONSE

The tree has been likened to a tower supporting an array of solar collectors (Wilson and Archer 1979). But it is much more supple than a tower, especially when small. Many young walnut trees develop straight, single stems, but others may become crooked or multiple-stemmed as the result of insect, animal, or weather damage. Yet, there is a tendency for such trees to straighten and for one leader of a multileader tree to gain dominance (Schlesinger and Bey 1978). Thus, many trees will overcome apparent form defects by themselves if left alone.

Removing some of the tree's solar collectors can reduce growth. Basically, pruning of live branches is a dwarfing practice (MacDaniels 1973). The greater the proportion of the live crown removed, the greater the chance of an undesirable response by the tree. This response could be reduced growth or the tree's attempt to compensate for the loss of its solar collectors by excessive height growth or by production of new branches on the bole (sprouting).

Pruning also causes wounds (Shigo *et al.* 1979). While the wound is open, disease organisms may gain entry and cause decay or discoloration of the wood. Wound healing involves the isolation of the wounded area (compartmentalization) and the closure of the wound by new wood overgrowing the wound. This process may result in zones of weakness in the wood that can lead to ring shake.

Black walnut does not prune itself well, even under the crowded conditions that are best for natural pruning. Especially under short-rotation intensive culture, artificial pruning of live branches or dead branches and stubs will be needed for veneer production. However, only those selected as potential crop trees will need to be pruned.

PRUNING PRACTICES

Corrective pruning.--Correcting potential form defects, especially multiple leader problems, is usually the first use of pruning in walnut plantings (Bey 1976, Beineke 1977, Clark 1966). The objective is to produce trees with straight, single stems. If two or more leaders are competing for dominance, all but one are removed. When no high-quality leader is present, the tree can be cut (coppiced) near the groundline, and the best leader can then be selected from the resulting stump sprouts. The major concern with corrective pruning is that removing too much of the live crown of a small tree may reduce growth or create new stem-form problems.

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The immediate, apparent benefits from corrective pruning may not last. von Althen (1977) found that seedlings severely injured by a June frost benefited from pruning or coppicing. Three years after treatment, 42 percent of the coppiced trees and 31 percent of the pruned trees were classified as excellent or good, but only 11 percent of the untreated trees were so classified. However, a study in southern Illinois[2] showed that the apparent improvement in tree form soon after treatment may disappear. Trees planted in 1967 were coppiced in 1969, 1970, and 1972, or not at all. Half of the trees were correctively pruned as needed beginning in 1967 and continuing until 1975. Tree form ratings in 1976 showed no significant effects of corrective pruning but trees coppiced in 1972 had significantly better form. However, by 1978 there were no significant differences in tree quality or between any of the treatments (table 1).

Corrective pruning can have a dwarfing effect. In von Althen's study (1977), the coppiced trees were 11 percent shorter and 20 percent smaller in diameter than the control trees after 4 years. The pruned trees were 3 percent shorter and 4 percent smaller. In the southern Illinois study, both tree height and diameter were significantly reduced by coppicing in 1972 but not by corrective pruning (table 2). Moreover, potential crop trees, identified on the basis of both size and quality, were more numerous within the untreated group than within any of the other treatment groups (table 3).

Table 2.--Average tree size in 1978 for Illinois study.

Year coppiced	Tree size: Diameter breast height: Not pruned	Tree size: Diameter breast height: Pruned	Tree size: Height: Not pruned	Tree size: Height: Pruned
	- - - cm - - -		- - - m - - - -	
Not coppiced	6.6	6.7	4.7	4.5
1969	6.8	5.9	4.6	4.3
1970	6.0	6.3	4.1	4.3
1972	4.9	4.8	3.8	3.7

Table 3.--Potential crop trees within each treatment group

Year coppiced	Crop trees[1]: Not pruned	Crop trees[1]: Pruned
	- - - - Percent - - - -	
Not coppiced	44	37
1969	26	32
1970	32	32
1972	16	16

[1] Trees that were average or above average in quality and size.

Table 1.--Comparison of tree quality in 1978 for Illinois study

Year coppiced	Tree quality: Excellent and good[1]: Not pruned	Tree quality: Excellent and good[1]: Pruned	Tree quality: Fair: Not pruned	Tree quality: Fair: Pruned	Tree quality: Poor and impossible: Not pruned	Tree quality: Poor and impossible: Pruned
	- - - - - - - - - - -		Percent	- - - - - -	- - - - - - -	
Not coppiced	44	37	26	33	30	30
1969	37	37	47	16	16	47
1970	58	37	26	42	16	21
1972	58	53	26	15	16	32

[1] The trees were rated on a scale of 1 to 10 as to their potential to develop into high-quality trees.

Thus, corrective pruning should be practiced with restraint, if at all. Generally not all trees are needed for crop trees.

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[2] Study No. NC-1108, CH-422, data on file at the Forestry Sciences Laboratory, Carbondale, IL.

Because many trees will "correct" themselves within a year or two after developing a form problem, delay in pruning may result in the disappearance of the need for it. If a tree is pruned, the least amount needed to do the job should be done. And coppicing in March, April, or early May will result in less growth loss than if done in June or July.[3]

Lateral pruning.--The objective of lateral pruning is to remove obstacles (branches or stubs) to the formation of clear, defect-free wood on the lower stem of a tree. Basic to the development of pruning recommendations are the following considerations: (1) tree growth should not be reduced by the removal of too many live branches at any one time, and (2) wound healing should be encouraged.

Clark and Seidel (1961) found that 14-year-old trees could be heavily pruned once without significantly reducing growth. Ten years after treatment, trees pruned of 75 percent of their live crowns had grown as much in diameter as trees pruned by lesser amounts or left unpruned. However, annual pruning for 6 consecutive years reduced tree diameter when 80 percent of the bole was cleared (table 4). Trees planted in 1969 were first pruned in 1975. Three years of annual pruning did not reduce tree size (Funk 1979). However, continued treatment for an additional 3 years resulted in smaller diameter trees when 80 percent of the bole was cleared, although tree height was not significantly affected. Diameter growth at breast height during the sixth year was significantly less for the 80 percent pruned trees than for lesser treatments (table 5).

Table 4.--Tree size after 3 and 6 years of annual pruning

Percent of height pruned	Height		Diameter at 0.3 m		Diameter at breast height	
	3 years	6 years	3 years	6 years	3 years	6 years
	- - - - m - - - -		- - - - - - - - - - cm - - - - - - - - -			
0	3.3	4.5	7.8	11.0	4.9	7.8
20	3.2	4.3	7.2	10.0	4.3	7.3
40	3.4	4.5	7.5	10.4	4.8	7.7
60	3.6	4.9	7.5	10.3	5.3	8.0
80	3.6	4.8	6.5	8.6	4.5	6.6

Table 5.--Treatment response during third and sixth years of annual pruning

Percent of height pruned	DBH growth	No. sprouts	
	6th year	3rd year	6th year
	cm		
0	1.2	0.1	0.1
20	1.0	0.2	0.0
40	0.9	0.6	0.4
60	0.8	1.3	2.9
80	0.6	6.7	10.7

The tree may respond to heavy pruning by producing sprouts. Clark and Seidel (1961) noted sprouts on 50 percent of the trees pruned of 75 percent of their live crowns, but only 6 percent of the trees pruned of 25 percent of their live crowns produced sprouts. Funk (1979) found an average of 6.7 sprouts per tree for the 80 percent treatment in the third year, and 10.7 new sprouts were produced during the sixth year of the study (table 5). This rebuilding of the live crown may help a tree maintain its growth rate, but it negates the potential benefits of pruning for the production of clear wood.

The wounds that result from either natural or artificial pruning must heal cleanly if the objectives of pruning are to be met. The extent of internal defects (staining and ring-shake zones) is related to the size of the wound, the number of wounds within a segment of the bole, and the season of year when the wounds are made (Shigo *et al*. 1978, Shigo *et al*. 1979, Smith 1980). Branch collars that form around dead or dying branches are part of the healing process, and thus removing these collars rewounds the tree (Shigo et al. 1979). Open wounds are infection courts for disease organisms such as wood decay fungi.

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[3] Data on file at the Forestry Sciences Laboratory, Carbondale, IL.

Heavy pruning can also lower tree quality, primarily because of the additional wounds created by the pruning of sprouts. In the southern Illinois study, annual, repeated pruning to clear 80 percent of the bole resulted in significantly fewer high-quality trees and more lower quality trees (table 6). On the other hand, no pruning and clearing only 20 percent of the bole also resulted in fewer high-quality trees than the 40-percent and 60-percent treatments (table 6).

Table 6.--Tree quality[1] after 6 years of annual pruning

Percent of height pruned	Excellent and good	Fair	Poor and impossible
	- - - - -	Percent - - - - - -	
0	33	57	10
20	28	62	10
40	54	33	13
60	47	35	18
80	23	42	35

[1] See footnote for table 1.

For best results, lateral pruning should be done in stages, beginning when the trees (and thus the branches) are small (3 to 4 m tall). Between 40 to 50 percent of the tree height should remain with branches. If clusters of branches are present, not all branches should be removed at one time. Pruning in the spring just before bud break avoids the fall spore production period of many disease organisms and minimizes the time before the wound begins to close. And spring wounds result in less discolored and abnormal wood than fall wounds (Smith 1980). If branch collars are present, pruning should remove the branch flush to the outer edge of the collar, not flush to the main stem.

Periodic pruning should continue until the desired clear length is obtained. Theoretical economic analyses generally support a 5.2 m clear length for veneer production and a 2.6 m clear length for nut production (Schlesinger and Funk 1977).

SUMMARY

Patience and understanding are the keys to pruning for quality. Generally, corrective pruning appears to be of little or no value in intensive culture, although there may be a few exceptions. Allowing trees to straighten naturally if possible and removing the low-quality trees in thinnings will normally result in a high-quality plantation. Careful, timely lateral pruning of potential crop trees will result in the development of clear wood and high-value trees.

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PRINCIPLES OF MANAGING BLACK WALNUT IN NATURAL STANDS[1]

Burnell C. Fischer[2]

Abstract.—The management of black walnut in natural stands is basically the combination of strategies normally employed in managing natural stands and the intensive cultural practices developed for plantations. These dual strategies, if carefully thought out in the planning process and then implemented, can result in the successful regeneration, growth and development of black walnut trees in natural woodlands.

INTRODUCTION

The intensive culture of black walnut plantations tends to dominate the discussion at a walnut meeting. However, timber production from natural woodlands as a management objective provides significantly more income to private, nonindustrial woodland owners than plantations.

Black walnut trees are usually a very small component of natural stands, generally appearing as scattered single trees or in small isolated groups. However, because of its potential high timber value, full consideration should be given to the possibility of incorporating the intensive culture of individual black walnut trees into the management of natural woodlands.

The objectives of this paper are two-fold. First, I wish to briefly review the steps necessary in developing a forest management plan for a natural woodland and the special considerations that can be made for black walnut tree management. Secondly, I will comment on several cultural practices for black walnut tree management in natural stands.

Management Planning

Most "forest management" in natural woodlands has been custodial in nature. That is, timber is harvested when it is merchantable and desirable for the owner, a new stand is then allowed to regenerate and grow as it will, and timber is again harvested when it becomes merchantable and advantageous to the owner. This type of management requires little, if any planning and results in very few timber management expenditures for the woodland owner. However, custodial management usually results in relatively few, widely spaced (in time) financial returns for the woodland owner. Also, such management generally does not favor the regeneration, development and growth of black walnut trees. This is particularly true when the forest management practiced is "partial cutting", where a residual stand of small and/or lower quality trees is left.

Managing timber, whether in natural stands or plantations, is a major project requiring a high degree of planning. This planning should result in the development of a forest management plan for the woodland and the consideration of the position of the woodland in relation to the other activities (investments) of the woodland owner. Both of these steps are of vital importance because of the extended time period resources are tied up before either a return is realized or the accumulated wealth in the timber and land is passed on.

A forest management plan is essential if the woodland owner is to maximize current income and wealth accumulation within the forest's biological constraints and site limitations, and his landownership objectives. As with the management of any investment, professional guidance and assistance is strongly recommended. Unless the landowner is trained in forestry he should seek the advice and skills of professional foresters. Foresters working for the State, Cooperative Extension Service, Soil Conservation Service, forestry consultants and industrial foresters can all be helpful.

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The development of a forest management plan can be explained as a four step process. The first and continuing step is that made by the woodland owner in clearly defining his ownership objectives. Foresters and other professionals can aid in this decision making process by proposing different alternatives and projected potential incomes from the forest. However, it must be emphasized that the final objectives be those of the woodland owner and not the assisting forestry professional.

Second is the completion of an inventory. This is simply the gathering of the data necessary to evaluate the woodland potentials and opportunities, so that timber management strategies such as thinning schedules, cutting budgets, planting regimes, improvement cuttings, logging road construction, timber tax management, and individual black walnut tree culture can be developed. The data gathering can be divided into two parts. The first part, sometimes called a reconnaissance cruise, consists of the determination of property boundaries, an accurate calculation of acreage, determination of soil and topographic conditions, procurement of maps and aerial photos of the woodland, an accounting of property taxes and other nonmanagement costs of holding the land and a description of the land-use history of the woodland. The more completely this first part of the inventory process is carried out, the more successful the data collected in the "timber cruise" in the second part of the inventory can be interpreted and utilized in developing the forest management plan.

To the person interested in black walnut two aspects of the reconnaissance cruise are of particular importance. First is the soil survey. By delineating the differing soil conditions for a woodland, the woodland owner can determine which sites are suitable for black walnut trees. This should prevent future errors in establishing and managing black walnut "off-site". The second aspect is that of land-use history. A thorough analysis of past timber sales, and management activities may indicate if the woodland previously contained higher populations of black walnut than at present.

The second part of the inventory process is the "timber cruise". The sampling intensity of the timber cruise is related to the ownership objectives and characteristics of the woodland. The timber cruise should be conducted by a forestry professional. In a timber cruise the forester determines the species, diameter, height, quality, vigor and past growth rate of sample trees. The data collected on the timber cruise can be utilized in determining the structure (tree size distribution), stocking (density), pulpwood and/or sawtimber volume, present value, growth potential and earning potential of the whole woodland as well as for separate portions (stands) of the woodland.

Because of the potential high market value and increased management activity directed toward black walnut trees it may be wise to more intensively sample the walnut tree population in a natural woodland. The ultimate would be to identify and record each walnut tree and its location in the woodland. This intensity may not be justified in many situations but careful consideration should be given to sampling intensity by a woodland owner and his forester. For example, intensively inventorying the more valuable trees would be of great help in establishing the financial basis should a loss of trees occur.

The third step is the actual development of a forest management plan. This written plan is the combining of the ownership objectives and inventory data. The final plan should include a description of the woodland, a statement of ownership objectives and goals, maps and aerial photos, summaries of inventory data, a timber/cash flow analysis, and a 5 to 10 year annual plan of work. A separate portion of the plan may be devoted to the more intensive cultural management of individual or groups of black walnut trees. Most woodland management plans appear rather standardized with little individuality, such as a separate walnut portion. This usually means the landowner has not identified his objectives but followed the ideas of a forester. Finally, additional provisions for updating and revising the plan, as well as for additional inventory data should be clearly indicated.

The fourth and final step is a continuing task for the woodland owner. He must implement the plan. Also on a regular basis he must record work progress, all expenses and incomes, review and plan for future work schedules, and evaluate the plan's continued desirability.

As the woodland owner evaluates his woodland management operation he should continue to include and consider the woodland investment as part of his total investment portfolio. This will require the woodland owner to review his present and projected returns and expenses with his tax accountant and financial advisors. This will allow for the woodland owner to balance the long-term and asset accumulation aspects of his timberland with his investment portfolio and estate planning for maximum efficiency and profitability.

Cultural Practices

Timber production inherently implies growing trees for harvest. Forest management proceeds on the basic assumption that the vegetation on any site normally tends to extend itself aggressively to occupy the available growing space. If the vegetation fills the growing space, the only way that the forest can be changed or controlled is by removing (i.e. cutting) trees. Thus, cutting is important not only as a means of harvesting trees for income, it is the means by which forests are re-established and tended.

Basically, cuttings are made to either promote the growth of desirable trees already in existence - an intermediate cutting, or provide room for the establishment of new trees - a reproduction/ harvest cutting. Both of these types of cuttings can be used to increase the numbers and growth of black walnut trees in a natural woodland.

Black walnut require nearly full sunlight to survive and grow as a seedling or sapling. In fully stocked forests it must be in a dominant or codominant crown position to maintain itself. Thus, cultural practices directed towards growing existing black walnut or the establishment of new seedlings must be concerned with this intolerance to shading (Schlesinger and Funk 1977).

Intermediate Cuttings

Intermediate cuttings are made during the long time period between the establishment of a new stand of trees and its eventual harvest. Intermediate cuttings vary in objectives. Thinnings primarily regulate stand growth by varying stand density. Release and improvement cuttings are designed to regulate the species composition and improve the quality of very young and older stands. Pruning of branches results in improved future individual tree stem quality.

Thinnings are desirable to control stand density, particularly in even-aged stands. Studies have shown that trees, even in older sawtimber sized stands, respond with increased diameter growth after thinning (Hilt, 1979). Stocking guides for a number of species including black walnut are presently available (Schlesinger and Funk 1977).

Release cuttings, particularly to stimulate the growth of selected hardwood crop trees in stands less than 10 years old, are of questionable value. Such release cuttings have not significantly improved height or diameter growth or length of clear stem, nor prevented crown-class regression in black cherry and yellow poplar following treatment (Smith, 1979). Some researchers now suggest that entry into young even-aged hardwood stands less than 20 years old may be unsuccessful in stimulating growth response. However, if the objective to enter young stands is to change species composition (i.e., remove dominant undesirable species) then such a treatment <u>may</u> still be possible.

Also, grapevine control in such young stands may be required to reduce damage `and allow future crop trees to develop. Grapevines can be a significant hinderance to young stands, particularly on very productive sites (Trimble and Tryon, 1979; Smith 1979).

Improvement cuttings (commonly called TSI if not a timber harvest) are generally made in previously unmanaged stands and take the form of removing cull trees or low-value species. The goal of such an operation is to increase future stand value by removing trees of little or no economic value and by providing space in which higher quality and high-value species can develop. Black walnut trees have been shown to be an excellent "candidate" tree to favor in TSI (Phares and Williams, 1971).

A concern that has recently arisen with TSI is the potential problem of "flashback" when using picloram (Tordan 101R) in stands. Flashback refers to the herbicide damage to adjacent untreated vegetation via root grafts or soil moisture movement. Yellow poplar is particularly sensitive to picloram. Black walnut has generally not shown to have this sensitivity problem. Practices that may avert the problem include monitoring dosage rates so that excess amounts of herbicide are not applied to injected trees, girdling trees rather than injecting herbicides and using alternative herbicides such as glyphosate (Roundup).[3]

Many landowners have invested time and money in pruning because of the veneer and high quality sawlog potential of black walnut. Pruning in plantations is usually necessary, especially those of wider spacing (Beineke, 1977). This is less of a problem in natural stands, however, pruning can be considered as an investment alternative. In theory this is a prudent investment because as a result of pruning, veneer/lumber-grade recovery of individual trees can be improved, with a resulting value increase of pruned trees over that of unpruned trees. However, in practice the landowner may not be rewarded for his pruning costs at the time of sale and harvest, so the decision to prune, as with any investment decision, must be carefully considered. Remember, pruning does not increase the growth rate of the tree! Only the reduction of surrounding competition improves individual tree growth. Pruning is simply a cultural treatment that should increase the potential stumpage value of a tree.

Planting in Natural Stands

Natural woodlands usually contain relatively few black walnut trees. Yet, many woodland sites are capable of growing black walnut. Since the natural regeneration of black walnut is a slow and "chancy" process, many woodland owners wish to "sweeten" the mix by planting black walnut trees after removing residual trees in a regeneration cutting.

Clearcutting or at least the creation of large openings (areas larger than 2-4 tree heights in diameter) is recommended as the best site preparation method prior to planting black walnut in a woodland. Such cutting creates an area large enough that open conditions are created. This is essential for black walnut. Following the planting of black walnut, the real management begins. Studies (Krajick 1975; Hilt 1977) and field experience continue to demonstrate that cultural treatments to control the competing dense sprout, shrub and herbaceous cover on previously forested sites is required if significant numbers of planted black walnut trees are to survive and grow to a dominant crown position. A second and often fatally ignored cultural practice is the maintenance of the opening/patch clearcutting over time. Smaller dimension openings, which are generally favored by woodland owners with small land holdings, must be periodically enlarged by cutting the border overstory trees. If ignored, the subsequent growth of residual overstory trees bordering a forest opening can dramatically reduce direct solar radiation levels. Fischer (1979) projected that small circular forested openings of 0.5 and 1.0 tree height dimensions had direct solar radiation reduced 21% and 17% in 5 years and 71% and 30% in 10 years based on average height and crown width increments of perimeter trees in upland hardwoods.

SUMMARY

The management of black walnut in natural stands is basically the combination of strategies normally employed in managing natural stands and the intensive cultural practices developed for plantations. These dual strategies, if carefully thought out in the planning process and then implemented, can result in the successful regeneration, growth and development of black walnut trees in natural woodlands.

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GROWTH OF BLACK WALNUT IN A FERTILIZED PLANTATION[1]

J. M. Braun and W. R. Byrnes[2]

Abstract.—Height and D.B.H. growth has averaged 2.2 ft/yr and 0.44 in/yr, respectively, for a well-managed, fertilized walnut plantation located on a moderately fertile site. Growth of the best 15% of the stand has averaged 2.7 ft/yr and 0.54 in/yr for height and D.B.H., respectively. The plantation was fertilized with N, P and K three times since planting in 1968, and yearly measurements of height and D.B.H. were made through 1977 and again in 1980. Statistical analysis failed to detect any meaningful growth response associated with fertilizer treatments, and there are no significant trends displayed by the data. The evidence in this study suggests that fertilizer amendments are not needed during the establishment of black walnut plantations located on good sites. This study is also discussed briefly as a case history of the growth and management potential for a walnut plantation.

INTRODUCTION

The intensive management of black walnut (Juglans nigra L.) in natural stands and plantations is of concern to many people today as an investment opportunity. Interest in black walnut has existed for many years due to the high stumpage prices that black walnut commands. The techniques needed to intensively manage black walnut, especially in plantations, have gradually developed during the last two decades. Improvement in management factors such as site selection and preparation, planting methods, spacing, interplanting with various nurse and agronomic crops, insect, disease, and weed control, corrective pruning, as well as the economic aspects of walnut management have been researched and the results and recommendations widely disseminated. Significant strides also have been made in genetic improvement of black walnut, primarily through selection and vegetative propagation. Finally, improved nursery management has produced higher quality black walnut planting stock.

Fertilization is another factor recognized as potentially significant for improving the growth of black walnut. At the time this study was initiated, 1967, there was very little information published relative to field fertilization of black walnut. Detailed study of the effects of fertilization in young plantations was considered of paramount importance and interest. The purpose of this study was to quantify the growth responses of a young black walnut plantation to various rates of nitrogen, phosphorus, and potassium fertilization.

LITERATURE REVIEW

Despite a broad base of experience in forest fertilization in some parts of the world and in some regions of our country, practical knowledge of field fertilization of black walnut is still fragmentary. Similarly, basic information on the nutritional requirements of black walnut is incomplete.

Based on greenhouse experiments with black walnut, Hacskaylo et al. (1969) described visual nutrient deficiency symptoms, normal leaf characteristics, and the foliar nutrient concentrations associated with each condition. This basic information is particularly useful for validating the condition of normal foliage. However, since site requirements of black walnut are well known, it is unlikely that nutrient deficiencies severe enough to cause recognizable deficiency symptoms will occur in a well-located walnut plantation. If nutrient deficiencies do occur they are more likely in the range of "hidden hunger." In this condition, nutrient deficiencies reduce growth but are not severe enough to produce distinctive visual symptoms.

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Phares and Finn (1972) prepared a list of tentative critical foliar nutrient levels for black walnut trees. Foliar levels below 2.00% N, 0.10% P, and 0.75% K were classed as deficient for these elements, with the strong likelyhood of a growth response to nutrient applications. Intermediate values, where fertilizer may or may not elicit a response were given as 2.00-2.60% N, 0.10-0.25% P, and 0.75-1.30% K. Presentation of these critical values is a definite step in the right direction, but to our knowledge these data have not received extensive field testing.

The feasibility of fertilizing black walnut at the time of planting appears to be related to the suitability of the site for walnut. Ponder (1980) studied walnut on Wakeland silt loam, a somewhat poorly drained soil, that was a marginal site for walnut. Fertilization at time-of-planting stimulated both height and diameter growth of the trees. However, growth did not equal that of black walnut planted on good sites. Other studies on sites suitable for walnut (Byrnes 1966, Schneider et al. 1970, and Williams 1974) have tested a wide range of planting methods, and weed control techniques in conjunction with various fertilization treatments at time-of-planting. The consensus opinion is that walnut seedlings planted on good sites do not exhibit significant or practical growth responses to fertilization at time-of-planting, therefore, fertilization was not recommended at this stage. Williams (1974) reported that fertilization reduced survival and growth of the planted seedlings. In this case, seedling roots probably were burned by fertilizer salts placed in the planting hole (1 ounce 8-32-8 tree). It was also apparent however that competing weeds stimulated by the fertilizer suppressed some walnut seedlings.

The Managers Handbook for Black Walnut (Schlesinger and Funk 1977) states that fertilization of pole-size trees is likely to provide the best economic returns. Schlesinger and Funk also caution, however, that "not much is yet known about fertilization," and "It is not possible to make specific recommendations for specific soils at the present time . . ."

Neely et al. (1970) examined a 22-year-old walnut plantation growing on Plainfield sand; a droughty soil low in organic matter. Three yearly surface applications of N at 2600 lb/A resulted in a D.B.H. growth response of 254% after the third year. The diameter growth rate of fertilized trees amounted to 0.26 in/yr but returned to the pre-treatment level of 0.07 in/yr within two years after the final fertilizer application. Treatment with a complete fertilizer (N, P, and K) improved diameter growth only 180% during the same period.

Von Althen (1976a) thinned and fertilized a 27-year-old plantation of black walnut growing on former agricultural land in Ontario, Canada. A complete fertilizer was applied at rates of 450-218-200 lb/A of N-P-K, respectively. Foliar N and P increased while K concentrations decreased 1-year after treatment. By the end of the third growing season, foliar nutrient concentrations returned to pre-fertilization levels. The treatment had negligible effect on trees of average basal area. However, considering only the largest 100 trees/A (the probable future crop trees), fertilization increased the average diameter and height by 27% and 22%, respectively.

Maeglin et al. (1977) fertilized two 40 year old stands of black walnut to ascertain the effects of nitrogen fertilizer on growth and log quality. They concluded high fertility bottomland sites should not be fertilized as the control trees grew more then those fertilized. On upland sites fertilization increased diameter growth, but not to a statistically significant degree. It was noted that log quality of unfertilized trees on the upland site suffered due to sprouting along the lower bole. This sprouting may have been suppressed by the fertilization which would result in a significant increase in the quality of those stems.

METHODS

This study was located on the Martell Experimental Forest of Purdue University about 10 miles west of West Lafayette in Tippecanoe County, Indiana. The soil type is Genesee silt loam (Fluventic Eutrochrept), a deep, neutral to slightly alkaline, well drained soil derived from stratified loamy and silty alluvium washed from upland areas of Wisconsin glacial till. The site is nearly level and occupies a second terrace of the Wabash River. The S.C.S. soil interpretation record for Genesee silt loam indicates that black walnut is suitable for planting. Other site selection criteria (Carmean 1966, Losche

1973a) also indicate that this soil/site was suitable for black walnut. The area had a past history of agricultural cropping and grazing, but had lain fallow for several years prior to the initiation of this study.

In early April 1968, 1-0 seedlings from the Indiana state nursery were planted in augered holes on an 8 by 8-foot spacing. The seedlings were subjected to a severe late frost in early May 1968, therefore, initial fertilizer application was delayed until the following year. Twenty-three fertilizer treatments composed of various combinations of N-P-K were applied in Spring 1969 (Table 1). Nutrient elements were applied in the following forms: N as ammoniom nitrate, P as triple superphosphate, and K as mutriate of potash. The 23 selected treatments comprise an incomplete factorial experiment in a triple cube design with four replications. Each axis of the cube can be considered to represent one of the applied nutrient elements, i.e. N, P, or K and the amount of that element applied indicates a point along that axis. This particular design, proposed by Iowa State University statisticians, was utilized because it gives good estimates of the linear and quadratic coefficients of the main effects i.e. N, P, or K response as well as the interaction between these elements.

At the time of planting, every other tree in each row and column of the plantation was designated as a buffer tree. Buffer trees remained untreated, and served to isolate the treated trees and to minimize the possibility of fertilizer movement between trees treated differently. The buffer trees were cut in January 1973, resulting in the current plantation spacing of 16 by 16-feet (fig. 1).

Repeat fertilizer treatments were applied during spring 1971 and spring 1975. The fertilizer was surface-broadcast on an 8 by 8-foot square plot (64 sq. ft.) centered on each treatment tree. Each fertilizer treatment was applied to four trees within a block (replicate).

This plantation has been intensively managed throughout its life. Prompted by the severe freeze in 1968, the plantation received frost protection during the spring of 1970 and 1971. This was accomplished by igniting petroleum-coke bricks on nights that damaging frosts were anticipated. This provided a low smoke cover and reduced back radiation from the soil. The treatment was successful in minimizing frost damage.

Mechanical cultivation several times each summer has been used to control competing vegetation. Chemical methods of weed control were not used due to possible interactions with the ferilizer treatments.

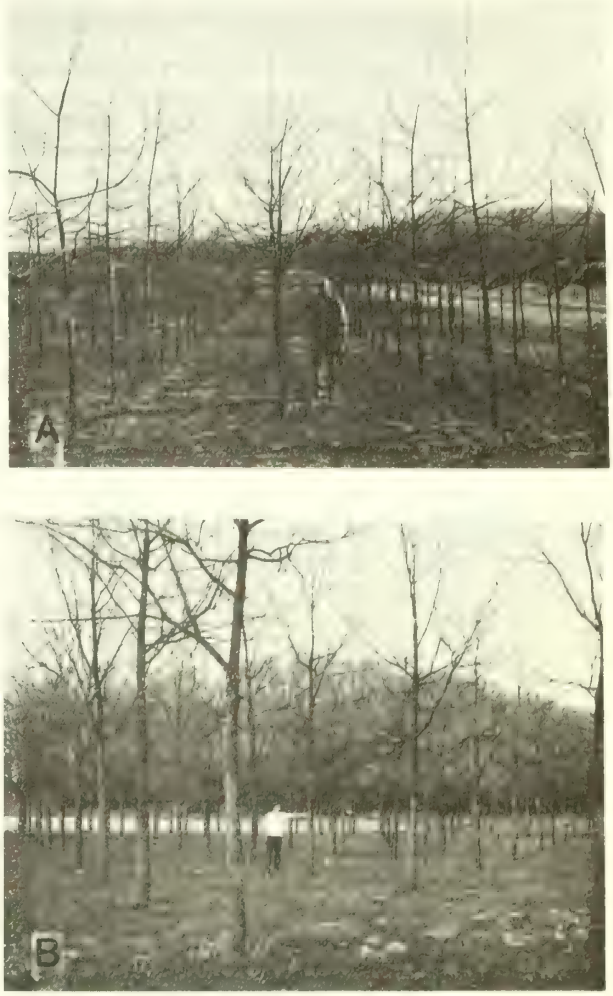

Figure 1.—Fertilized black walnut plantation located at Purdue University, Martell Forest: A Block 1, Dec. 1972, 8 x 8-foot spacing; B Block 2, March 1981, 16 x 16-foot spacing.

Corrective pruning to improve stem form has been applied periodically since 1971. Stem pruning also was initiated in 1971 to encourage development of clear bole wood. The plantation has not been irrigated at any time and no pesticides have been used for insect or disease control. Some top breakage of trees has occurred periodically during severe storms.

Table 1.--Mean[1] survival, height, diameter-at-breast height (DBH), and total volume of black walnut by fertilizer treatment in fall 1980.

Fertilizer Applied			Survival	Total Height	D.B.H.	Total Volume[2]
N	P	K				
(lbs./A)			(%)	(ft.)	(in.)	(cu. ft.)
0	0	0	94	26.2	5.4	2.1
0	0	140	94	28.5	5.9	2.6
0	60	0	100	29.9	5.7	2.4
0	60	140	100	31.2	6.3	3.0
400	0	0	100	29.9	5.9	2.6
400	0	0	100	28.5	5.6	2.4
400	60	0	100	28.5	5.7	2.4
400	60	140	94	29.9	6.2	2.8
200	30	70	100	28.9	5.7	2.4
0	30	70	100	26.2	5.5	2.2
400	30	70	87	27.9	5.8	2.4
200	0	70	100	31.5	6.0	2.7
200	60	70	94	25.6	4.9	1.7
200	30	0	100	32.5	6.1	3.0
200	30	140	100	28.9	5.6	2.4
100	15	35	100	30.8	5.9	2.7
300	45	105	100	28.5	6.1	2.7
100	15	105	100	32.2	6.3	3.0
300	45	35	100	26.9	5.6	2.2
300	15	35	100	27.9	5.7	2.4
100	45	35	100	31.8	6.3	3.0
100	45	105	100	25.6	5.2	1.9
300	15	105	100	27.2	5.5	2.2
All treatments			98	28.9	5.8	2.5

[1] Mean of four replications

[2] Formulae from Todhunter et al. (1979)

$$V = -2.86094 + 0.14366 \sqrt{(D^2 \times H) + 400}$$

where: V = total stem volume in cubic feet
D = DBH in inches
H = total height in feet

Soil samples were collected before the first fertilizer application in 1969, in 1970, and again prior to fertilization in 1975. These samples were analyzed for available P and exchangeable K. In addition, the 1975 samples were tested for KCl extractable NH_4^+ and NO_3^-. All tests were made by the soil testing laboratory at Purdue University.

The total height and D.B.H. of all fertilized trees were measured in the fall each year through 1977 and in 1980. The growth response of the four trees comprising an experimental unit was averaged and represents the treatment response for a given block.

RESULTS AND DISCUSSION

Data on total height and D.B.H. of the fertilized trees was subjected to statistical analysis at the P=0.05 level. The individual linear and quadratic effects for the three nutrient elements as well as their interactions were isolated by use of multiple regression. Not a single instance of a statistically significant growth response related to fertilizer treatment of black walnut was detected on these soil and site conditions.

In a similar analysis, year-by-year height and D.B.H. growth was examined. In fall 1975, the year of the last fertilizer application, a significant height growth response was noted for N and K (P=0.05). However, these responses were not of a practical magnitude, and there was no carryover into subsequent growing seasons.

Table 1 displays results of the fall 1980 measurements by fertilizer treatment. For all fertilizer levels and blocks combined, the average values for height, D.B.H., and volume are 28.9 feet, 5.8 inches, and 2.5 cubic feet, respectively. It is evident that there is a wide range of values about these means, and there is no apparent relationship between the measured values and the applied fertilizer. Survival was excellent, ranging from 87 to 100 percent among fertilizer levels, with a mean of 98 percent for all treatments and replicates combined.

There are several reasons why we believe the walnut plantation in this study did not respond to fertilization. Most importantly, the fertilizer added during this study amounted to only a fraction of the available nutrients on this fertile site. Analysis of surface samples collected in 1969 prior to the first fertilizer application indicated 54 and 168 lb/A of available P and exchangeable K, respectively. In 1970 the total soil profile was analyzed from one of the control plots, i.e. no fertilizer added. The available P and exchangeable K in the whole profile amounted to 355 lb/A and 960 lb/A, respectively. Table 2 presents the results of soil analysis from samples taken in the spring of 1975 prior to the third fertilization. Previous fertilizer additions had not materially increased the supply of available soil nutrients for any element (P=.05). Consequently, if fertilization cannot measurably alter the site, it cannot be expected to measurably influence the growth of vegetation on that site.

Secondly, as stated above, soil analysis indicated that the native site was moderately to highly fertile. Thus, despite the high nutrient demands that black walnut makes on a planting site, the site was capable of supplying these needs. The best evidence for this is the fact that the growth of the control trees has not differed significantly (P=0.05) from trees treated with any of the fertilizer combinations (Table 2).

Finally, there is a statistical explanation why growth differences were not found. The triple cube design allowed examination of all the individual factors of interest, and their interactions. This was accomplished with only 95 treatment units (a group of four treated trees within a block) whereas a complete factorial design would have required 500 treatment units. Although the design is widely used for industrial applications, the large variation inherent in biological systems reduces the ability of this design to detect treatment differences.[1] Thus, although treatment differences may actually exist, they are of such a small magnitude that they cannot be separated from the natural variation in growth of this plantation.

The main objective of this study was realized by concluding that fertilization of young black walnut stands, less than 13-years-old, planted on a good walnut site, will not yield a growth response at fertilizer levels used in this study. In addition, this study provides the basis for an excellent case history of tree growth in a well managed walnut plantation.

Figure 2 shows the total height and D.B.H. over the life of the plantation, 1968 to 1980. For both height and D.B.H., a rapid,

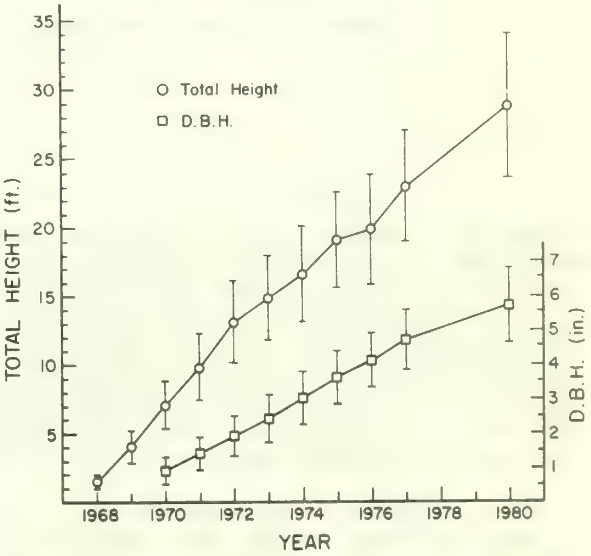

Figure 2.—Mean total height and D.B.H. (diameter-at-breast-height) for fertilized black walnut by year for the period 1968-1980, at Purdue Martell Forest.

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[1] Personal communication with Dr. Virgil Anderson, Professor of Statistics, Purdue University.

Table 2.—Soil N, P, and K, and current height, DBH, and total volume by increasing levels of applied nutrient.

Fertilizer Applied	Soil[1] Analysis Spring 1975	Fall 1980		
		Height	D.B.H.	Total Volume
lb./A	lb./A	ft.	in.	cu. ft.
		Nitrogen		
0	119	28.5	5.7	2.5
100	131	30.2	5.9	2.6
200	127	29.5	5.7	2.4
300	117	27.6	5.7	2.4
400	136	28.9	5.8	2.5
		Phosphorus		
0	76	28.9	5.7	2.5
15	79	29.5	5.8	2.6
30	91	28.9	5.7	2.5
45	91	28.2	5.7	2.5
60	96	28.2	5.7	2.5
		Potassium		
0	194	29.5	5.7	2.5
35	216	29.5	5.9	2.6
70	222	27.9	5.5	2.3
105	224	28.2	5.7	2.4
140	232	29.5	5.9	2.6

[1] Available N and P and exchangeable K, for surface samples

relatively uniform growth rate has been maintained since planting. Average annual growth rates over the 13-year period have been 2.2 ft/yr and 0.44 in/yr for total height and D.B.H., respectively. All seedlings attained the D.B.H. height (4.5 feet above the ground) by 1970. The vertical bars in figure 2 represent ± 1 standard deviation about the mean; it is evident that this variation increased as the trees grew older.

The distribution in total height and D.B.H. by 3-foot height and 1-inch D.B.H. classes, respectively, for all plantation trees in fall 1980 is shown in figure 3. Over 75% of the trees currently exceed 27 feet in height, and about one-third of the stand is taller than 33 feet. Diameter distribution indicates that over 50% of the trees have a D.B.H. greater than 6 inches.

In an effort to judge how well the Martell plantation was growing, growth data from several sources was assembled for comparison (Table 3). The sources listed represent a wide range of soil and climatic

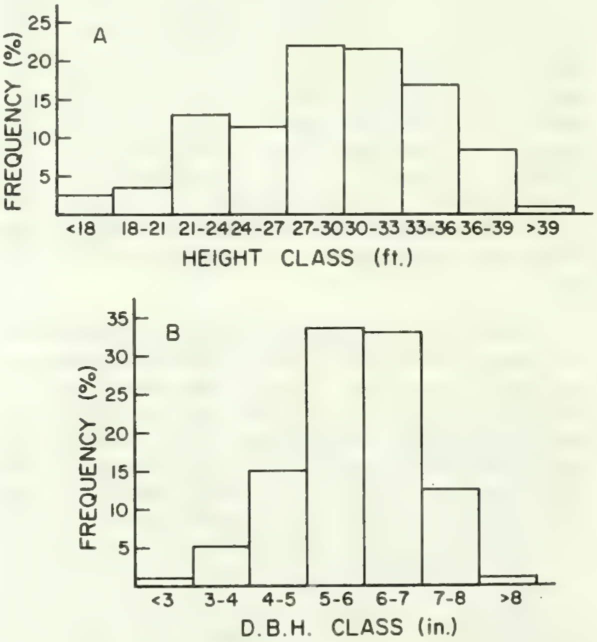

Figure 3.—Total height and D.B.H. distribution in fall 1980 for fertilized black walnut plantation at Purdue Martell Forest.

Table 3.--Average annual growth rates of trees in a fertilized black walnut plantation at Martell Forest compared to selected references.

Study	Location	Annual Growth Rate HT	Annual Growth Rate D.B.H.	Stand Age	Comments
		ft/yr	in/yr	yrs.	
Martell Forest					
overall $\bar{x}$	Central Indiana	2.2	.44	13	
best 15%		2.7	.54		
Selected References					
Bey (1980)	Central States	0.9 - 2.6	.22 - .56	10	Provenance study
best 20%		1.9	.38		
Brinkman (1966)	Illinois	1.5		58	Unmanaged plantation
Byrnes, et al. (1973)	Central Indiana	1.0 - 1.7	.11 - .26	8 - 10	Weed control treatments
Carmean	S. Illinois	0.7 - 2.9	*	25	Site study
Clark et al. (1979)	S. Indiana	1.2 - 1.9	.18 - .28	12	Interplant. w/N fixers
Funk et al. (1979)	S. Indiana	0.8 - 2.5	.11 - .45	9	Interplan. w/autumn olive
Heflin (1965)	Missouri	*	.16	88	Unmanaged plantation
Krajicek et al. (1974)	S. Indiana, Iowa	0.6 - 1.7	*	3 - 5	Weed control treatments
Krajicek (1975)	Illinois	1.2 - 2.7	.10 - .31	7	Plantation on clearcut
Losche (1973b)	S. Illinois	1.4 - 2.1	.16 - .26	23 - 28	
Phares (1973)	*	*	.05 - .26	25 - 60+	Release/thinning study
Ponder (1980)	Illinois	1.0 - 1.4	*	7	Fert. rate & placement
von Althen (1976a)	Ontario, Canada	1.1 - 1.8	.16 - .28	36	Thinning & fert. study
von Althen (1976b)	Ontario, Canada	0.9 - 1.3	*	3 - 5	Planting methods study

*No data reported

conditions, stand origin, treatments, and intensity of management. Efforts were made to find and include references reporting fast growth rates. It is evident that the fertilized walnut plantation studied here is growing as well as the best walnut trees studied elsewhere. Given the intensive management this plantation has received, we believe the unimproved stock used in this study has grown at a rate close to the maximum potential rate achievable on this site.

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INTERACTION OF NITROGEN FERTILIZATION AND CHEMICAL WEED CONTROL ON FOUR-YEAR VOLUME GROWTH OF A BLACK WALNUT PLANTATION[1]

P. E. Pope, H. A. Holt, and W. R. Chaney[2]

Abstract.--Four year height, diameter and volume growth of a 16-year-old (treated at age 12) black walnut (Juglans nigra L.) plantation was significantly influenced by N-fertilization and chemical weed control. The greatest four year cumulative diameter increment (1.75 in.) and total volume growth .568 cu. ft.) occurred on trees fertilized with 100 lbs. nitrogen per acre in combination with weed control. Weed control alone resulted in a 38% increase in volume growth above untreated trees after four years whereas weed control in conjunction with 100 lbs. nitrogen per acre produced a 121% increase in volume growth. Changes in foliar nitrogen levels corresponded closely with changes in volume growth.

INTRODUCTION

Both private and industrial woodland owners have shown increasing interest in planting and growing black walnut (Juglans nigra L.). Expectations of high return on investment are certainly a stimulus for this activity. Cultural techniques to hasten growth and shorten rotation are of potential value. Considerable research has been done on genetic improvement, spacing and planting methods, weed control, pruning, and fertilization, but many questions still remain (Bey and Williams, 1976; Dickson, 1971; Holt and Voeller, 1975; Krajicek, 1971, 1975; Krajicek and Williams, 1971; Schlesinger and Funk, 1977; and Williams, 1974). This paper reports a study of the effect of nitrogen fertilization and chemical weed control on growth of 12-year-old black walnut trees for three years after treatment. Most studies on fertilization have dealt with the response of trees to nutrients applied at the time of planting. The intent of this research was to ascertain the growth response to nitrogen fertilization and weed control of established, plantation grown black walnut trees.

METHODS

The study was established in a 12-year-old black walnut plantation planted in Morgan County, Indiana in the spring of 1965. The trees were planted at 11 x 11 ft. spacing on a Martinsville silt loam soil (Typic Hapludalfs, fine-loamy, mixed, mesic). A combination of nitrogen fertilization and/or chemical weed control was applied to one-half of the plantation on May 20 and 21, 1977. The experiment was arranged in a split plot with three replications of each treatment and unequal observations per replication. Data were analyzed by analysis of variance (ANOVA) and Duncan's new multiple range test. Nitrogen treatments constituted the whole plot (0.20 acres) and chemical weed control was applied in 4 ft. bands down either side of the planted rows to one-half of each fertilized plot (0.04 acres). Nitrogen as urea was broadcast by hand at rates equivalent to 0, 50, or 100 lbs. of elemental nitrogen/acre. Weed control treatments were none and a combination of glyphosate [N-(phosphonomethyl)glycine] and simazine [2-chloro-4,6-bis(ethylamino)-S-triazine], each at 4 lb. ai/A in water. To allow for border trees, 18 trees were measured in each replication of no weed control treatments whereas 12 trees were measured in each replication of weed control treatments. On May 1, 1977, prior to treatment application, trees averaged 20 ft. in height and 3.5 in. diameter at 4.5 ft. above the ground and had a per acre volume of 283.53 ft^3. Total height and diameter measurements were taken after the growing season for each of four years following treatment. These parameters were used to compute volume in cubic feet and expressed on a per acre basis with 360 trees per acre. Volume computation utilized an equation developed for seedling and sapling black walnut; $V = -2.86094 + 0.14366 \sqrt{D^2H+400}$, where V = total stem volume in cubic feet, D = diameter at 4.5 ft. in inches, and H = height in feet (Todhunter, et al., 1979).

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Foliage samples were collected and analyzed for nitrogen by micro-kjeldahl distillation (Wilde, et al., 1972) prior to treatment and in mid-September for two years following treatment.

RESULTS

Average annual diameter increments and total diameter increment over 4 years are shown in Table 1. Except for the 1979 growing season, weed control alone, without nitrogen fertilization, did not affect diameter growth. Likewise, the total diameter increment for the four year measurement period was not significantly greater than no weed control. Weed control in conjunction with nitrogen fertilization did result in greater diameter growth over the four year measurement period. Except for the 1980 growing season, trees that received nitrogen and weed control grew more than those that received the same rate of nitrogen fertilization but no chemical weed control, although statistically significant differences at $\alpha = 0.05$ were evident in only two of the treatment combinations. The greatest increase in diameter growth occurred on trees fertilized with 100 lbs. nitrogen/acre with chemical weed control. These trees increased in diameter 0.82 in. more than the unfertilized trees with no weed control. For trees receiving no chemical weed control, fertilization with urea at 100 lbs/acre resulted in more diameter growth than attained by trees not fertilized or those receiving 50 lbs. nitrogen/acre. The differences were greatest for the 1980 growing season and the four year growth accumulation. Approximately 50 to 65 percent of the radial increment growth in all treatments, including the control, occurred in 1979 and 80, three and four years after treatment with 32-42 percent occurring during the wet 1979 growing season.

The data for 1980 are difficult to interpret. The diameter growth data suggest a decline in the rate of incremental growth, however, the severe drought during the 1980 growing season could have limited the growth that would have been attained under more normal conditions.

Chemical weed control alone did not affect the height growth increment of the 12-year-old (presently 16-year-old) black walnut trees (Table 2) nor did nitrogen fertilization in the absence of weed control. Trees that received 100 lbs. nitrogen/acre and chemical weed control had a significantly greater height growth increment in 1977, 1980 and in cumulative growth for the four-year period than trees in plots with no fertilizer or weed control.

Table 1.--Influence of N-fertilization and chemical weed control on the diameter growth increment of a black walnut plantation.

Fertilizer Rate (lbs N/A)	Weed Control	Diameter Increment (in.)				
		Year				
		'77	'78	'79	'80	Total
0	No	0.21a[1]	0.20a	0.34a	0.18a	0.93a
	Yes	0.21a	0.33ab	0.55b	0.20a	1.29ab
50	No	0.25a	0.18a	0.48ab	0.33b	1.24ab
	Yes	0.34b	0.38b	0.51ab	0.28ab	1.51b
100	No	0.32ab	0.30ab	0.61b	0.49c	1.72c
	Yes	0.36b	0.37b	0.63b	0.39b	1.75c

[1] Column values not followed by the same letter are significantly different (Duncan's New Multiple Range Test, $\alpha = 0.05$).

Table 2.--Effect of N fertilization and chemical weed control on annual incremental height growth of black walnut.

Fertilizer Rate (lbs N/A)	Weed Control	Height Increment (ft.)				
		Year				
		'77	'78	'79	'80	Total
0	No	2.2a[1]	0.8a	2.0a	1.3a	6.6a
	Yes	2.8a	0.8a	3.4ab	0.9a	7.9a
50	No	3.0a	1.3a	1.4a	2.8ab	8.5ab
	Yes	2.9a	2.0a	2.6ab	3.6b	11.10ab
100	No	3.2ab	1.4a	4.3b	2.9ab	11.80ab
	Yes	4.5b	2.1a	3.8ab	3.1b	13.50b

[1] Column values not followed by the same letter are significantly different (Duncan's New Multiple Range Test, α = 0.05).

Volume increase of black walnut per acre during the four-year study period, like height and diameter growth, was unaffected by weed control alone (Table 3). Generally, per acre volume increment increased with increasing levels of nitrogen fertilization and weed control. Fertilization at 50 lbs. nitrogen/acre with weed control or fertilization at 100 lbs. nitrogen/acre with or without weed control significantly increased volume growth over that of untreated trees. The largest volume increment during the four-year study period occurred on trees that received chemical weed control and 100 lbs. nitrogen/acre. This treatment resulted in an additional 311 ft^3/acre when compared to the control treatment receiving no fertilizer or weed control. Increased growth response in the high nitrogen-weed control treatment relative to high nitrogen and no weed control was limited to the first growing season following treatment. The increased height and diameter growth combined with the multiplicative characteristic for volume calculations accounted for the increased volume of wood produced.

No differences in percent foliar nitrogen were evident in leaves collected on May 20, 1977, prior to treatment application (Table 4). At the end of the first growing season, September 1977, increased foliar nitrogen was found in response to both weed control and nitrogen application. Weed control alone resulted in increased foliar nitrogen in both

Table 3.--Effect of weed control and nitrogen fertilization applied in a 12-year-old black walnut plantation on annual and cumulative volume growth.

Fertilizer Rate (lbs N/A)	Weed Control	Per Acre Volume Increment (ft^3)				
		Year				
		'77	'78	'79	'80	Total
0	No	60.28a[1]	39.87a	78.50a	78.28a	256.93a
	Yes	68.30a	59.85ab	134.46b	91.89a	354.49ab
50	No	77.57ab	43.52a	97.31ab	142.74b	361.14ab
	Yes	91.20b	85.02b	110.41ab	169.89b	456.52b
100	No	92.02b	63.64ab	158.88c	212.51c	527.05c
	Yes	117.01c	84.82b	154.76c	211.31c	567.90c

[1] Column values not followed by the same letter are significantly different (Duncan's New Multiple Range Test, α = 0.05).

Table 4.--Percent foliar nitrogen in black walnut in relation to nitrogen fertilization and weed control.

Fertilizer Rate (lbs N/A)	Weed Control	Date		
		May '77	Sept. '77	Sept. '78
0	No	2.36a[1]	2.26a	2.48a
	Yes	2.51a	2.59b	2.85b
50	No	2.63a	2.66bc	2.91b
	Yes	2.58a	2.95c	3.42bc
100	No	2.41a	2.49b	3.46bc
	Yes	2.53a	2.84c	3.61c

[1] Column values not followed by the same letter are significantly different (Duncan's New Multiple Range Test, $P < .05$).

the first and second years after treatment. When 50 lbs. nitrogen/acre were added in conjunction with weed control, the levels of foliar nitrogen were greater than that of leaves of control trees at the end of the first season. When compared to the weed control only treatment, weed control applied with 50 lbs. nitrogen/acre did not significantly increase foliar nitrogen levels in September, 1978. At the end of the first growing season, 100 lbs. nitrogen/acre with weed control resulted in levels of foliar nitrogen that were much higher than control trees and this difference existed for two years after application.

DISCUSSION

Black walnut growth response to nitrogen application was anticipated based on results of Phares and Finn (1971). They predicted no probable growth response of black walnut trees from adding nitrogen when foliar level is above 2.6 percent, some response at foliar levels of 2.0 to 2.6 percent, and a likely response at levels below 2.0 percent foliar nitrogen. Foliar nitrogen levels for trees in this study were in the high side of the medium range, about 2.4 to 2.6% (Table 4). The first growing season after nitrogen fertilization, nitrogen levels increased to a point where no additional response was expected except in those trees that did not receive weed control. This study clearly shows that weeds are very competitive sinks for available nitrogen. Weed control treatments alone resulted in significant increases in tree foliar nitrogen levels. Nitrogen application increased foliar nitrogen levels above that of unfertilized trees around which weeds were controlled only when done in conjunction with weed control. Fertilization without weed control was no more effective than weed control alone at the end of the first growing season. The benefits of 50 lbs. nitrogen/acre and weed control were lost in the second year after treatment. This was due to the reestablishment of competing weeds on the weed control plots in the second year. On the plots that received 100 lbs. nitrogen/acre, luxuriant amounts of nitrogen were apparently still available for both weeds and trees during the second growing season.

The increased levels of foliar nitrogen in response to treatments relate closely to the volume growth increments that were found. These results support the suggestion by Russell (1961) that nitrogen generally affects leaf area of plants and that over a considerable range of nitrogen supply the amount of leaf area available for photosynthesis in proportional to the nitrogen applied. Ellis and von Althen (1973) who worked with 30 to 85-year-old natural stands of several hardwood trees in southern Ontario also concluded that nitrogenous fertilizer increased diameter growth through increased leaf area.

Nitrogen fertilization of established trees does not always produce increased growth. A 40-year-old stand of black walnut in southern Wisconsin on an upland site did not show a significant increase in diameter growth when fertilized with 500 lbs/acre of elemental nitrogen as ammonium nitrate. The same rate of nitrogen application on a fertile bottomland site reduced the rate of diameter growth below that of unfertilized trees (Maeglin, et al., 1977). Phares[2] (unpublished data) found a similar retardation of black walnut growth in Indiana. Trees of a 60 to 80-year-old stand growing on a fertile bottomland site grew less when fertilized with nitrogen than trees not fertilized. Nevertheless, Schlesinger and Funk (1977) stated that fertilization of pole-size trees is likely to provide the best economic returns and that nitrogen is the most promising nutrient to apply. They suggested that it may be necessary to refertilize approximately every 5 years to maintain growth stimulation. They also emphasize that fertilization should be considered a supplement to other cultural practices, and cannot be expected to compensate for other limiting factors such as light and moisture. The results of the present study reinforce these observations since nitrogen was found to significantly increase diameter, height, and volume growth of small pole-size trees and was most effective when done in combination with weed control.

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CONCLUSIONS

For the specific conditions of this study, significant increases in volume growth of a young black walnut plantation can be achieved by fertilizing with 100 lbs/acre nitrogen. The largest volume increase was recorded for plantations fertilized with 100 lb/acre N, plus weed control. While fertilization with 50 lb/acre N and/or weed control improve volume growth over the unfertilized control these growth differences were not significantly different.

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EFFECTS OF SELECTED COVER CROPS ON THE GROWTH OF BLACK WALNUT

P. L. Roth and R. J. Mitchell

Abstract.--This study was initiated to investigate the effects of selected cover crops on the growth of black walnut (Juglans nigra L.). The cover crops tested were: Poa pratensis L., Lolium multiflorum L., Phleum pratense L., Festuca arundinacea Schreb., Trifolium repens L., Lespedeza stipulacea Maxim., Melilotus officinalis (L.) Lam., Lespedeza cuneata Dumont Maxim. and a clean-cultivated control. Cover crops significantly affected the height and caliper growth of black walnut throughout the study period. Black walnut grown in clean-cultivated plots exhibited superior height and diameter. Within cover crop treatments, the height and caliper growth of black walnut grown with Lespedeza cuneata was the greatest while walnut grown in association with Festuca arundinacea showed the poorest growth.

Additional Keywords.--Height growth, caliper growth, cover crop, Juglans nigra

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INTRODUCTION

Black walnut (Julans nigra L.) is the most valuable of native American woods. Accelerated reduction in the growing stock of quality black walnut, coupled with increasing demands placed upon the resource, have resulted in escalating prices for both logs and standing timber (Callahan and Smith 1974). If this shortage of black walnut lumber and veneer is to be alleviated, methods oriented toward the intensive management of this species must be investigated.

For continued good growth, walnut trees require deep, well drained, loamy soils (Losche 1973). Such sites normally have the potential to produce agronomic crops such as corn, soybeans and forage crops. Combining the management of forage crops with black walnut allows a landowner to produce short term returns to supplement income, until nut and wood crops can be realized.

A number of articles have suggested that this type of "multicropping" management is economically sound (Garrett et al. 1976, Callahan and Smith 1974), although it is warned that the data used for the economic analysis are "incomplete and slightly speculative" (Callahan and Smith 1974). This study was initiated to provide data pertaining to the growth response of black walnut grown in association with selected forage cover crops.

EXPERIMENTAL METHODS

Site Description

The experimental site was located at the Forest Tree Improvement Center two miles west of Carbondale, Illinois. The soil is classified as a Hosmer Silt Loam, a light colored forest soil, developed from loessal parent material. The soil has a fragipan at a depth of 0.6 m which restricts root depth and the movement of air and water.

Cover Crop Establishment

The cover crops consisted of: two short grasses, Kentucky bluegrass (Poa pratensis L.) and annual ryegrass (Lolium multiflorum L.); two tall grasses, timothy (Phleum pratense L.) and tall fescue (Festuca arundinacea Schreb.); two short legumes, white clover (Trifolium repens L.) and common lespedeza (Lespedeza officinalis (L.) Lam.) and sericea lespedeza (Lespedeza cuneata Dumont Maxim.). The control treatment was clean-cultivated throughout the growing season. In the fall of 1973 the cover crops were hand sown at locally recommended agronomic rates. In the spring of 1974 any areas that did not establish were resown to establish 100% cover of the specific crop in each plot.

Black Walnut Establishment

Seed for the study was collected in the fall of 1973. Parent trees were located within a ten-mile radius of Carbondale, Illinois. No standards of quality were set for the parent trees; however, all trees were judged to be of average quality as standing saw timber. Walnut seeds were pregerminated and planted in the spring of 1974. Seeds were planted on 0.9 x 1.5 m initial spacing. At the end of the 1974 and 1979 growing season trees were removed for root/shoot ratio determination so that final spacing was 1.8 x 1.5 m.

Experimental Design

The plantation was established as a split-split plot factorial design with ten replications. These replications were put in a series of five blocks. Each replication was 28.7 m wide by 19.2 m long, and contained nine randomly located treatments. The treatments were eight cover crop species plus a control that was kept free of vegetation through clean-cultivation. Each treatment was 1.5 m wide by 19.2 m long. On five randomly selected replications (one per block), the cover crops were mowed at three-week intervals during the growing season. On the remaining five replications, the cover crops were allowed to grow undisturbed.

Data Collection

Height and caliper (10 cm above ground line) measurements were recorded at the end of the 1974, 1978, and 1979 growing seasons. In late June, 1979 a team of four investigators optically estimated the percent cover by forage species in each treatment.

Data Analysis

The data were analyzed to detect significant differences by analysis of variance. If significant differences were present, Duncan's Multiple Range Comparison test was employed to perform multiple comparison among the treatments. The significance level was set at alpha = 0.05 for all statistical tests.

RESULTS AND DISCUSSION

Cover Crop Assessment

Species of cover crops varied greatly in their ability to maintain themselves in association with black walnut over the six year study period. The degree of compatibility of the eight species to the mowing treatment also varied (Table 1). Kentucky bluegrass and tall fescue were the grasses that showed the greatest compatibility with black walnut. Kentucky bluegrass (a short grass) maintained itself substantially better under the influence of the mowing while all other crop species were less abundant in the mowed replications. Apparently, the low growing morphology resulted in a competitive advantage for Kentucky bluegrass when mowing occurred. Tall fescue maintained itself well in both the mowed and the unmowed condition, and was the major invader in plots sowed to other crop species. Timothy and annual ryegrass were essentially eliminated from the plantation by stand age six. This may have been due to the susceptibility to juglone or the inability to compete with the aggressive fescue sod. Sericea lespedeza was the only legume that maintained itself well in the unmowed plots. In the mowed plots it appeared to be more susceptible to competition, especially from tall fescue. Sweet clover, white clover, and common lespedeza were unable to maintain themselves through the study period.

Height and Caliper Growth

Significant differences in mean height growth of black walnut trees associated with the various cover crop treatments were observed throughout the study (Table 2). After the 1974 growing season black walnut trees growing on the clean cultivated plots showed superior growth relative to the other cover treatments. Differences in height of black walnut among cover crop treatments after the first growing season were small, although some trends may be discerned. Timothy, white clover, sweet clover, common lespedeza and annual ryegrass tended to compete less with black walnut than did sericea lespedeza, Kentucky bluegrass and tall fescue. Differences in height growth were accentuated by the end of the 1978 growing season, with trees grown in association with annual rye exhibiting a slowing of height growth and black walnut grown in sericea lespedeza showing accelerated mean height development. This reduction in growth of black walnut in annual ryegrass plots may have been due to the failure of annual rye

Table 1.--Cover crop percentage of relative cover in 1979, six years after seeding

Cover Crop	Kentucky blue-grass	Annual rye-grass	Timothy	Tall fescue	White clover	Sericea lespedeza	Sweet clover	Common lespedeza
	Percentage of Relative Cover							
Kentucky bluegrass	29.5	8.3	7.5	5.3	6.5	-	4.3	8.8
Annual ryegrass	-	-	-	-	-	-	-	-
Timothy	-	0.5	1.5	-	-	-	0.3	-
Tall fescue	44.5	51.6	63.0	70.0	72.3	5.3	49.0	57.0
White clover	-	-	-	-	-	-	-	-
Sericea lespedeza	1.7	-	0.5	7.5	1.8	87.0	2.0	1.0
Sweet clover	-	-	-	-	-	-	8.0	3.0
Common lespedeza	1.5	-	0.5	0.3	1.5	-	-	-
Invading weedy species	22.8	39.7	27.0	16.9	17.9	7.7	36.4	30.2
Kentucky bluegrass	53.6	9.3	9.8	14.5	4.8	8.2	15.5	8.8
Annual ryegrass	-	-	-	-	-	-	-	-
Timothy	-	0.3	-	-	-	-	-	-
Tall fescue	27.2	69.8	59.5	66.5	68.0	36.0	44.8	57.0
White clover	-	-	1.0	-	1.0	-	-	3.0
Sericea lespedeza	-	-	-	-	-	31.8	10.0	1.0
Sweet clover	-	-	-	-	-	-	-	-
Common lespedeza	-	1.5	2.3	0.8	3.0	0.5	5.5	-
Invading weedy species	19.2	19.3	27.4	18.2	23.2	23.5	24.2	30.2

Table 2.--Height and caliper growth of black walnut intercropped with eight forage species and grown under clean cultivation

Cover Crop	1974		1978		1979	
	Height (cm)	Caliper (mm)	Height (cm)	Caliper (mm)	Height (cm)	Caliper (mm)
Kentucky bluegrass	20.4[1] c	2.3 c	73.6 cd	14.5 cd	96.7 cd	21.1 b
Annual ryegrass	21.6 bc	2.3 c	74.2 c	12.4 d	83.5 d	15.8 c
Timothy	24.0 b	2.6 b	95.9 b	17.8 bc	115.4 bc	22.9 b
Tall fescue	20.2 c	2.2 c	63.7 d	10.6 d	81.4 d	15.8 c
White clover	22.6 bc	2.7 b	104.7 a	20.3 b	121.8 b	26.3 b
Common lespedeza	21.9 bc	2.3 c	102.0 b	17.9 bc	116.0 bc	23.8 b
Sweet clover	22.6 c	2.3 c	102.8 b	19.0 bc	119.5 b	24.8 b
Sericea lespedeza	21.0 c	2.2 c	91.4 bc	17.2 bc	112.3 b	23.5 b
Control	30.7 a	3.9 a	123.2 a	26.0 a	148.2 a	35.2 a

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[1] Each number followed by a common letter (a, b, c, d) is not significantly different at the P = 0.05 confidence level.

and the subsequent invasion of tall fescue observed in 1974. The clean cultivated control outperformed all other treatments during the 1978 and 1979 growing season. As a group, black walnut grown with sericea lespedeza, white clover, sweet clover, common lespedeza and timothy treatments performed better than walnut grown with Kentucky bluegrass, annual ryegrass, and tall fescue. The stunting of the growth of black walnut when grown in association with fescue that was observed in this study, and in a study by Todhunter and Beineke (1979), may be due to competition for mineral nutrients and water, or to an allelopathic reaction. Walters and Gilmore (1976) found that fescue suppressed the growth of sweet gum (Liquidambar styraciflua L.) through an allelopathic mechanism.

Mowing had no significant effect on height or diameter growth of black walnut. Although mowing did affect the ability of forage crops to maintain themselves throughout the study period (Table 1).

Data presented in Table 2 on caliper growth of black walnut show relationships similar to those observed in height growth. Clean cultivation resulted in superior caliper growth of black walnut throughout the study. The caliper growth of walnut associated with sericea lespedeza was initially retarded followed by a more rapid growth in the later stages of the study. Caliper growth of trees associated with fescue was the lowest of the cover crop treatments.

Biological and Managerial Considerations

The results of this study show significant differences in height and caliper growth of walnut among cover crop treatments. Although growth rates of black walnut in the clean-cultivated control treatment were superior, the energy necessary to maintain this condition and the potential for accelerated erosion would render this alternative less than desirable for prolonged time periods in most management situations. Sericea lespedeza was able to maintain itself well when grown in association with black walnut and walnut seedlings exhibited their greatest growth when associated with this forage species, relative to the other cover crop species. It is suspected that the early retardation of growth of black walnut when grown in association with sericea lespedeza could be eliminated by clean-cultivation during the first few years, allowing the walnut trees to grow to a height above that which the sericea lespedeza would reach (0.9 m), followed by seeding with sericea lespedeza. If the plantation is subject to moderate to high erosion potential the manager could keep an area (1 m diameter minimum) around the seedlings free of vegetation and seed with sericea lespedeza at the time of plantation establishments. Tall fescue tended to retard the growth of black walnut, subsequently it is not recommended as a cover crop in black walnut plantations during the early etablishment period.

White clover and sweet clover were unable to compete with the invading tall fescue. Fertilization and liming to adjust the fertility of the site to a more optimum level may have resulted in the clovers establishing and maintaining themselves, although more research is necessary before this species can be recommended for intercropping with black walnut.

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BLACK WALNUT SEED: FROM TREE TO SEEDLING[1]

Robert D. Williams[2]

Abstract--Recommendations are given for collecting seeds. Germination of unhulled nuts are compared with nuts hulled in large and small capacity hullers. Seed testing methods, including X-ray, are discussed; the importance of, as well as how to determine, seed moisture content is shown. Results from recent seed storage and stratification trials are presented.

Hog farmers brag that their consumers use everything but the squeal. Black walnut growers can be just as proud. They market the stem, root, and limb wood of walnut for veneer, lumber, and speciality products; the walnut kernels are food for man and animal. The walnut shells are used as abrasives for deburring, cleaning, and polishing; as additives in oil well drilling mud; and as filtering agents in smokestack scrubbers.[3] But the most important use of the nut is its role as seed, to perpetuate the species. Squirrels eat much seed, but they are also responsible for most of the natural reproduction of walnut through forgotten or unused food caches. Humans, too, consume some seed as food, but they also collect tons of seed each year (when it is available) for direct seeding or for producing seedlings at nurseries.

SEED COLLECTION

Some basic principles to remember when collecting walnut seed are:

1. Collect seed up to 150 miles south of the planting site (Bey 1980) or use the seed collection zones recommended by Deneke et al. (1980).
2. Keep records on the performance of progeny from individual seed trees. Seed and seedlings from local stands may perform very differently.
3. Choose straight, vigorous seed trees to increase chances of straight, vigorous progeny.
4. Collect after the husk begins to turn color.
5. Place collected nuts in porous bags to prevent heat buildup. Heat destroys the viability of the seed.
6. Keep seed as cool as possible until it is hulled. Hulling is not essential unless the seed is to be tested.
7. Don't waste time collecting seed from poor seed chances. Concentrate your efforts where seed is plentiful. Seed crops can be estimated by counting the number of trees that have seed in a sample of 10, and by counting the number of nuts per cluster. If 7 of the 10 trees have 1 nut per cluster or if 5 of the 10 trees have 2 or more nuts per cluster, there will be an average seed crop. If 7 or more of the 10 trees have 2 or more nuts per cluster, there will be a heavy crop.[3] Before collecting nuts, crack a few from each tree. If fewer than 6 of 10 nuts from a tree have good kernels, don't collect from that tree.

HULLING

Walnut seed should be hulled to perform the float and X-ray tests, to facilitate mechanical sowing, and to reduce bulk for seed stratification or storage. Seed may be hulled by hand or by mechanical huller.

Some hullers damage the germinative capacity of the seed. The nuts are forced up against a metal grill which rubs off the hull, or they are flailed with chains to break and loosen the hulls. Probably the net effect on the seed is influenced, too, by the quantity of seed in the huller at a given time. The fewer the seed the more punishment they take and the greater the probability that the seed will be damaged and not germinate.

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[1] Paper presented at the joint meeting of the Northern Nut Growers Association and the Walnut Council. Purdue University, West Lafayette, IN, August 13, 1981.

[2] Robert D. Williams, Principal Silviculturist, North Central For. Exp. Stn., Bedford, IN.

[3] Personal communication with Gus Rutledge, 1981. Hammons Products Company, Stockton, MO.

We conducted a study to determine whether either of the two hullers we used might destroy the germinative capacity of the seed. Our tests were conducted with small seedlots, which probably biased our findings in favor of the small huller. Because unhulled seed floats and unhulled seed was one of our variables, none of the seed was float tested. All seed was fall sown. Germination was 48 percent for unhulled seed, 60 percent for seed hulled in the small huller, and 25 percent for seed hulled in the big huller.[4] Although mechanical hullers may reduce germination, I believe germination of seed hulled in the big huller would have been higher if the huller had been run at normal capacity. Also, the float test will eliminate most of the bad seed, and hulled and float-tested seed will germinate more completely than unhulled seed.

SEED TESTING

To estimate the number of seedlings that will be produced, any sower should know what portion of his seed has the potential to germinate. Unfortunately, short of germinating the seed, only an estimate of germinative capacity is available. Walnut seed requires a minimum of 90 days' stratification, so germination tests take too long to be useful to anyone sowing seed in the fall, immediately after collection. In addition to the germination test, two standard tests and one relatively new test estimate seed viability: (1) the float test, (2) the cracking test, and (3) X-ray.

The float test separates filled from unfilled seed when hulled seed is placed in water. Air spaces in the unfilled seed cause it to float, while the filled, good seed sinks. To be effective, the float test should be conducted within 3 days after the seed is hulled. If too dry, even good seed will float.

The cracking test is the cracking of a randomly drawn number of seeds to examine their kernels. The viability of a seedlot is estimated by determining the percentage of seed filled with firm, well-developed, white endosperm. Bad seed contain distinctly shriveled kernels, or the kernels may be buff or tan, and some may give off a rancid odor. Some bad kernels may be watery or be filled with a thick, clear, or milky oozing liquid and give off a foul odor.

X-raying seed is a useful and relatively new method to determine more precisely the quality of the seed. Every seed is X-rayed and those seeds that do not show a filled seed cavity with well-defined outlines of the seed kernel on the radiograph are discarded. X-raying walnut seed is laborious, the film and processing are expensive, and the radiologist must be a skilled technician to improve over the results of the float test. For example, in one of our first X-ray studies, germination was 64 percent for unhulled seed, 60 percent for hulled, 72 percent for hulled and floated, and 74 percent for hulled, floated, and X-rayed seed. In a later study, which contained 10 seed sources, germination was 70 percent for unhulled seed, 69 percent for hulled, 80 percent for hulled and floated, and 75 percent for hulled, floated and X-rayed seed. Germination for the ten seed sources ranged from 53 to 86 percent.[4]

Both the float test and the X-ray test must be done soon after the seed is hulled. If allowed to dry longer than 3 days, much of the seed will float and the air pockets, which are one indication of bad seed, will show up on the radiographs. In one trial, after 8 days of drying, the float test indicated that all seed in some sources were bad. According to X-ray and cracking tests done on the same seed samples, X-ray showed that 83 percent of the seed was good and the cracking test showed that 89 percent was good.[4]

The ability of the radiologist to separate good from bad seed varies by seed source and drying time. Some seed sources are more photogenic than others and radiographs are more easily discernible. If dried too long, air pockets appear in radiographs of good seed causing them to appear bad. After 28 days of drying, all seed appeared bad on the radiographs.

SEED GERMINATION

Black walnut seed is dormant when it falls from the tree, and must be stratified before it will germinate. In temperate climates, such as Indiana, overwintering in the seedbed, after fall sowing, usually satisfies the seed's requirement for stratification and the seed germinates normally the following spring. Sometimes, however, seed does not germinate until after two winters in the seedbed. Second-year germination has been observed in nursery seedbeds and by those direct seeding the nuts in the field. Seed source plays an important role in stratification, so some of the northern seed sources might not germinate promptly or completely if fall-sown in southern nurseries without prior cold room stratification.

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[4] Data on file at Bedford, IN.

There are three primary methods of stratification. In addition to fall sowing, a natural stratification of the seed, we have used cold stratification and pit stratification. Our cold stratification was a cold storage room at the Vallonia Nursery with a temperature of 37° F. Hulled seed was dipped in water, allowed to drain up to 15 minutes, placed in 4 mil plastic bags, and closed with a wire tie before being placed in the cold room.

Pit stratification was accomplished by placing hulled seed in pits about 3 feet deep. In normal stratification, alternate layers of seed and about 2 inches of sand would be built up to within 6 inches of the soil surface.

Fall-sown seed usually germinates more promptly and more completely than either cold- or pit-stratified seed. In a study involving 10 seed sources, germination of fall-sown seed was 63 percent; germination of cold- and pit-stratified seed was 58 percent and 52 percent, respectively.[4] Germination by seed source ranged from 43 to 71 percent. In another study germination was 46 percent for fall-sown seed, 42 percent for cold-, and 28 percent for pit-stratified seed.[4] Because fall-sown seed germinates sooner in the spring, the 1-year-old seedlings are usually larger than those from spring-sown stratified seed.

Length of stratification is important, especially for greenhouse work or for seed preparation for spring sowing. All seed sources that we tried required at least 60 days in cold stratification. However, most seed sources germinate more completely after 90 days' stratification, and seed germinates most promptly after 120 days in stratification.[4]

MOISTURE CONTENT

Moisture content plays an important role in the behavior of black walnut seed. Seed moisture content must be reduced for cold storage, and dried seed must imbibe water before it will germinate. For example, 44 percent of presoaked seed with previously reduced moisture content germinated, but only 29 percent of nonsoaked seed germinated. Seed moisture content differs by seed source, too. For example, after 14 days of drying, moisture content of one seed source was reduced by 8 percent while moisture content of another was reduced 26 percent.[4]

Moisture content is easy to determine. First, weigh a sample of 5 nuts and a cloth bag large enough to hold the nuts; crack the nuts and place all pieces in the bag; place the bag of nuts in an oven preheated to 103° C; leave in the oven for 16 hours, then take out and reweigh (Bonner 1980). The formula for percent moisture content is:

$$\text{M.C.} = \frac{\text{wet weight} - \text{oven dry weight}}{\text{wet weight}} \times 100$$

To store nuts in a home refrigerator at about 40° F, moisture content should be reduced to about 30 percent. To store nuts in a home freezer where the temperature is about 0° F, seed moisture content should be reduced to about 17 percent (Williams 1971).

SEED STORAGE

Reliable, inexpensive seed storage techniques are needed for large seed quantities. Bumper seed crops occur locally in some years, but in other years no seed is produced. Walnut seed may be stored 1 full year in cold storage with little loss of viability (Williams 1971). However, walnut seed is so bulky that cold storage is too expensive for large seedlots. So we have been searching for an alternative storage method.

First, we tried ambient temperature storage.[4] Seed was sheltered from precipitation but subject to fluctuating temperatures in one location in Georgia, two locations in Illinois, three locations in Indiana, and one location in Minnesota. If kept in ambient temperature storage over winter, then placed in cold storage until it was fall-sown, some of the seed from each storage location germinated. But seed kept at ambient temperature the full year, did not germinate.

Next, we tried storing seed in root cellars.[4] Although there was a sharp loss in viability, some seed germinated after a full year in cellar storage. For example, seed collected from 10 southern Indiana seed sources in 1978 was stored in three different cellars and in pits dug at Indiana's Vallonia Nursery. After a full year in storage, the seed was fall-sown in the nursery. Germination of fresh seed from the same seed sources sown in the fall of 1978, right after collection, ranged from 58 percent for the poorest seed source to 95 percent for the best. Average germination was 81 percent. After a full year in storage, germination was 22, 23, and 24 percent for seed stored in the three cellars and 23 percent for seed stored in the pits.[4] Although 23 percent germination is not satisfactory, the cellar storage results are encouraging. If we use different kinds of bags, or manipulate the humidity, or provide some cooling, cellar storage may preserve seed viability at a satisfactory level.

SOWING SEED

Plantations may be established by direct seeding or by planting seedlings. To produce seedlings for transplanting in the field, the seedbed should be prepared in much the same way as preparing soil to sow corn or beans in a garden.

For natural stratification and best germination, sow the seed in the fall. To produce about 6 seedlings per square foot, sow 12 seeds per square foot (3 x 4 inch spacing) if seed tests indicate 50-percent germination. Adjust the sowing rate according to the seed quality. Seed should be covered with 1 1/2 to 2 inches of soil (a rule of thumb is to cover 2 times the diameter of the seed). If seed is sown in the spring, it should be stratified at least 90 days before sowing. For example, if seed is to be sown March 15, the seed should be placed in cold stratification by December 15. To protect the seed from predators, cover it with wire screening or lathe fencing.

If the seed is to be sown in the field, sow enough seed at each seed spot to ensure a seedling. If germination capacity is 50 percent, sow 2 seeds per seed spot. To protect the seed from predators, cover the seed spot with manure (Williams and Funk 1979) or with wire screen staked down over the seed. Sow the seed about 2 inches deep.

To shorten the time between sowing and seed germination, thus providing less time for rodents to pilfer the nuts, sow stratified seed in the spring. Use manure or screen wire over the seed to protect it from squirrels.

SUMMARY

There's still much to be learned about black walnut seed. But for best results we know to:

1. Collect seed up to 150 miles south of the planting site.
2. Remember that seed quality and development of seedlings from seed trees differ within local stands.
3. Collect from productive stands and high-quality trees.
4. Hull and float test within 3 days.
5. Use a huller with care because it may damage the seed and reduce its germinative capacity.
6. Sow seed the fall it's collected if possible, and never let the seed dry out excessively.
7. Stratify the seed in a cold room for at least 90 days before sowing when fall sowing is not possible.
8. Try storing surplus seed in cellars when cold storage is not available.

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A SCREENING OF VESICULAR-ARBUSCULAR (VA) MYCORRHIZAL FORMING FUNGI ON BLACK WALNUT SEEDLINGS[1]

M. W. Melichar*, H. E. Garrett and G. S. Cox[2]

Abstract.--The effects of VA mycorrhizal forming fungi on the growth and development of black walnut (Juglans nigra L.) were studied. Percentage infection, root dry weight, stem dry weight, total seedling dry weight, stem diameter and stem height, were determined for each seedling. Seedlings inoculated with Glomus microcarpus, Glomus microcarpus+Glomus fasciculatus, and Glomus microcarpus+Glomus etunicatus+Glomus fasciculatus demonstrated superior growth and development to those inoculated with other species or left uninoculated.

INTRODUCTION

The multitude of microorganisms which live on or near the feeder roots of trees, agronomic crops and other plant types interact with the plant roots to form a functional association which plays a vital role in many physiological processes. Microbial processes involve saprophytism, pathogenism and mutualism. The most universal mutualistic relationship of plants is the mycorrhizal association which involves various root-inhabiting fungi and plant feeder roots.

The benefits of mycorrhizae to plant growth and development are well documented for ectomycorrhizal tree species (Garrett, et al., 1979; Marx, 1979; Vlasov, 1955). However, fewer studies have been made on endomycorrhizal woody types (Kormanik, et al., 1979; Starkey and Brown, 1977). In particular, little information is available on the endomycorrhizal relationships of black walnut (Juglans nigra L.), the premier timber species of the eastern United States (Ponder, 1979). This is unfortunate since black walnut is noted for poor growth and development during the first two years after outplanting (Williams, 1970) and could benefit greatly from mycorrhizae. Moreover, the chances of natural colonization of walnut root systems under nursery conditions is low due to seedbed sterilization and the fact that endomycorrhizal spores are disseminated only through the soil. At best, recolonization of nursery beds is a slow process following sterilization. Without artificial reinoculation, the benefits of a mycorrhizal relationship are not forthcoming in advance of the invasion of the walnut root system by indigenous mycorrhizal fungi at the planting site. Unfortunately, with our limited knowledge of walnut mycorrhizal relationships, at present it is impossible to recommend a specific organism for artificial inoculation.

The objective of this study was to evaluate the effects of five vesicular-arbuscular (VA) endomycorrhizal fungi on the growth and development of black walnut seedlings.

MATERIALS AND METHODS

The study was conducted within a greenhouse at the University of Missouri-Columbia. Natural light conditions were utilized and temperatures ranged from 25-29 degrees Centigrade. The greenhouse was covered with a shadecloth which transmitted 50 percent of full sunlight.

Five VA mycorrhizal fungi, Glomus caledonius (Nicolson and Gerdemann), Glomus fasciculatus (Thaxter sensu Gerdemann), Glomus microcarpus (Tulasne and Tulasne), Glomus etunicatus (Becker and Gerdemann) and Glomus mosseae (Nicolson and Gerdemann), were used as inocula.

The inoculum was produced by growing each fungus in association with soybeans (Glycine max, Merrill) of the Clark variety. Potting soil was steam sterilized and soybean seeds surface sterilized in a 10 percent, sodium hypochlorite solution to minimize contamination. These open pot cultures were maintained in the greenhouse for 110 days until the soybeans flowered. After flowering, the aboveground portion of the soybean plant was removed. The remaining soil-root mixture was allowed to dry, ground, and placed in sterile containers for future use as inoculum.

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[2] *Research Forester, Kansas State University, Manhattan, Kansas. Associate Professor and Professor, respectively, Forestry Department, University of Missouri-Columbia.

To minimize genetic variability among the walnut seedlings, half-sib seed of the Thomas variety were selected for uniform size and used in all treatments. The seed were surface sterilized in a 10 percent hypochlorite solution for 60 seconds, rinsed twice in distilled water and pregerminated in sterile vermiculite prior to planting.

The soil mixture consisted of equal volumes of soil, peat and vermiculite. The mixture was steam sterilized at 100 degrees centigrade for a period of 45 to 60 minutes. The mixture was then placed in five-gallon pecan cans (nine inches in diameter, 20 inches deep). The containers were watered repeatedly for a period of ten days prior to inoculation and planting to insure that the entire soil profile was saturated.

Inoculation consisted of thoroughly mixing 400 milliliters of soybean VA inoculum throughout the sterilized soil:peat:vermiculite growth medium. In addition, a cone-shaped area was formed at the surface of the soil mixture and filled with 150 milliliters of inoculum. The germinated walnut was placed directly on top of the inoculum to insure taproot-inoculum contact. Five species of fungi, used either singly or in combination, were employed as inocula. The seven treatments were Glomus caledonius, Glomus mosseae, Glomus microcarpus, Glomus microcarpus (60%)-Glomus fasciculatus (38%), Glomus fasciculatus (56%)-Glomus microcarpus (32%), Glomus microcarpus (48%)-Glomus etunicatus (28%) and a noninoculated control (Table 1) -- the percentages given for the combination treatments represent the proportion of spores present of that particular spore type. The soil was saturated every three to five days throughout the study so that seedlings were never under any degree of water stress.

A completely randomized statistical design involving the seven mycorrhizal treatments was used. Each treatment was replicated three times with five seedlings in each replication, providing 15 seedlings in each treatment. All data were subjected to analysis of variance and the means were analyzed using Duncan's New Multiple Range Test at the 0.05 alpha level.

After 198 growing days, all seedlings were lifted by immersing the entire container in water and loosening the growth medium, thus enabling it to fall away from the root system. Care was taken to insure that the fine feeder roots were retained. Percentage infection, root dry weight, stem dry weight, stem height and stem diameter were determined for each seedling. Percentage infection was assessed by a modification of the root-slide technique of Starkey (1977).

RESULTS

Inoculation of container-grown black walnut successfully produced viable VA endomycorrhizal associations. Incorporation of soybean root fragments and fungal spores grown in open-pot-cultures yielded infection percentages greater than noninoculated controls in all treatments. The percentage mycorrhizal lateral roots ranged from a high of 66 in the _G. microcarpus_ (60)-_fasciculatus_ (38) treatment to a low of 11 in the control (Table 2). The infection in the control seedlings was attributed to a lack of complete soil sterilization during steaming and not to reinvasion. Inoculation with _G. microcarpus_ (60)-_fasciculatus_ (38), _G. caledonius_, _G. fasciculatus_ (56)-_microcarpus_ (32) and _G. microcarpus_ (48)-_etunicatus_ (28) all resulted in significant increases in infection over the control. Infection percentages were 66, 61, 61 and 54, respectively.

Inoculated seedlings also produced greater root dry weights than noninoculated control stock. _Glomus fasciculatus_ (56)-_microcarpus_ (32), _G. microcarpus_ (60)-_fasciculatus_ (38) and _G. microcarpus_ (48)-_etunicatus_ (28) treatments resulted in significant increases in dry weights of 118, 113 and 98 percent, respectively, over the control. Inoculation with the relatively pure culture of _G. microcarpus_ yielded seedlings 83 percent heavier than those produced in the noninoculated treatment.

An apparent correlation exists between percentage infection and root dry weight. Seedlings inoculated with _G. microcarpus_ (60)-_fasciculatus_ (38), _G. fasciculatus_ (56)-_microcarpus_ (32) and _G. microcarpus_ (48)-_etunicatus_ (28) all demonstrated increased root dry weight as a result of increased mycorrhizal infection. However, the root dry weight of _G. caledonius_ seedlings was only 51 grams, even though _caledonius_ produced the second highest infection percentage (61%). The increased absorptive root surface area of the mycorrhizal seedlings resulted in a significant increase in top growth.

Table 1.--Treatments consisting of six different isolates and/or combinations of VA mycorrhizal fungi (Glomus sp.) and a control which were used to inoculate black walnut seedlings.

Treatment name	Spore types and counts*					Total number of spores per 100 ml soil
	G. cale.	G. micro.	G. moss.	G. fasic.	G. etun.	
Control	-	-	-	-	-	-
G. caledonius	136	35	-	-	-	171
G. mosseae	8	-	49	3	-	60
G. microcarpus	21	89	-	-	-	110
G. micro (60)-fasic (38)	6	100	-	63	-	169
F. fascic (56)-micro (32)	12	34	-	59	-	105
G. micro (48)-etun (28)	-	63	-	33	36	132

*Number in ( ) indicates percentages of total number of spores present of that respective spore type for that particular treatment. G. cale.=Glomus caledonius, G. micro.=Glomus microcarpus, G. moss.=Glomus mosseae, G. fascic.=Glomus fasciculatus, G. etun.=Glomus etunicatus.

Table 2.--The effect of inoculation with VA mycorrhizal fungi (singularly and in combination) from the family Endogonaceae on growth of black walnut seedlings.

Treatment	Infection %	Root dry weight (gm)	Stem dry weight (gm)	Total dry weight (gm)	Stem diameter (cm)	Stem height (cm)
G. micro (60)-fasic (38)	66 a	102 ab (113)	5.5 a (53)	118.9 a (102)	.65 ab (14)	35.9 a (17)
G. fasic (56)-micro (32)	61 a	105 a (118)	5.5 a (53)	121.3 a (106)	.68 a (19)	34.9 ab (13)
G. micro (48)-etun (28)	54 abc	95 abc (98)	4.8 ab (33)	109.7 ab (86)	.64 ab (12)	32.1 ab (4)
G. microcarpus	37 bcd	88 abcd (83)	5.6 a (56)	121.8 a (107)	.65 ab (14)	30.4 ab (-1)
G. mosseae	33 bcd	70 abcd (46)	4.0 ab (11)	82.9 ab (41)	.60 bcd (5)	34.0 ab (10)
G. caledonius	61 ab	51 cd (6)	3.5 b (-3)	61.8 b (5)	.60 bcd (5)	31.6 ab (3)
Control	11 d	48 d	3.6 b	58.9 b	.57 d	30.8 ab

Means not sharing the same letter differ significantly at the alpha =0.05 level according to Duncan's New Multiple Range Test. Number in ( ) denotes the percentage difference from the control.

Mycorrhizal seedlings were consistently larger in diameter and of greater dry weight than those which were not inoculated (Table 2). The single exception was G. caledonius stock which averaged 0.1 g less weight than the nonmycorrhizal seedlings. Inoculation with G. fasciculatus (56)-microcarpus (32), G. microcarpus (60 -fasciculatus (38), G. microcarpus, and G. microcarpus (48)-etunicatus (28) significantly increased stem diameter 12 to 19 percent compared with controls.

Stem height was not affected as dramatically by inoculation as were many of the other growth features. No significant differences were observed between any of the mycorrhizal treatments and the controls. Seedlings inoculated with G. microcarpus (60)-fasciculatus (38), however, were 17 percent taller than the controls; G. fasciculatus (56)-microcarpus (32) and G. mosseae seedlings were 13 and 10 percent taller, respectively.

DISCUSSION

Endomycorrhizal inoculation of black walnut in containers is feasible under greenhouse conditions and, in all likelihood, could also be accomplished in nursery seedbeds. Our results indicate that a suitable inoculum for stimulation of the early development of endomycorrhizae on eastern black walnut may be prepared by grinding the soil and root systems of soybeans, which have been inoculated with one of several species of Glomus. Soil sterilization either by steaming or fumigation (a common nursery practice) will obviously decrease the chance of mycorrhizal development as demonstrated by the control seedlings which had only 11 percent of their root systems colonized.

The early development of endomycorrhizae on walnut seedlings in this study was associated with significant increases in growth and development. Inoculation with G. microcarpus provided an 83 percent increase in root dry weight over the noninoculated controls, while a combination of G. fasciculatus (56)-microcarpus (32) yielded a 118 percent increase. This increased root development is especially important in many Midwest soils, since it enables the seedling to better meet its moisture and nutrient needs.

A complementary relationship between inoculation, root development and shoot development was also pronounced after one growing season in this study. Inoculation with G. microcarpus, G. fasciculatus (56)-microcarpus (32) and G. microcarpus (60)-fasciculatus (38) provided increases in stem weight of more than 50 percent and increases in stem diameter from 12 to 19 percent. Although size is not necessarily a criterion of physiological condition, survival and growth after outplanting is better with larger stock. A common morphological feature used in grading nursery walnut planting stock is stem diameter. Seedlings 1/4-inch (0.64 cm) or larger in diameter survive better and grow faster than smaller ones following outplanting (Williams, 1970). Inoculation with G. microcarpus (60)-fasciculatus (38), G. fasciculatus (56)-microcarpus (32), G. microcarpus (48)-etunicatus (28) and G. microcarpus resulted in stem diameters of 0.65, 0.68, 0.64 and 0.65 cm, respectively. Control seedlings averaged only 0.56 cm which is less than the recommended 1/4-inch limit for culls.

CONCLUSIONS

This study indicates that walnut seedlings greater than 1/4-inch in diameter can be consistently produced by artificially inoculating soils with certain species of Glomus. Production of uniform nursery stock of this size could greatly reduce production costs by reducing the number of cull seedlings. In addition, such stock would exhibit greater survival and growth rates when outplanted.

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A SILVICULTURAL-ECONOMIC MODEL FOR BLACK WALNUT[1]

Warren H. Kincaid, William B. Kurtz and H. E. Garrett[2]

Abstract.--The level of profitability from investment in black walnut production is directly related to the level of management intensity. Five different management regimes ranging from walnut timber only to timber, nuts, soybeans, winter wheat, fescue hay and grazing are evaluated in terms of internal rate of return and present net worth. Management regimes are synthesized for two sites (SI-80 and SI-65) which support different annual diameter growth rates. Internal rates of return, from least- to most-intensive management, ranged from 6.68 percent to 15.91 percent on the higher quality (SI-80) site and from 4.26 to 13.00 percent on the lower quality (SI-65) site.

Silvicultural-economic relationships within black walnut management regimes are readily examined using a systems studies approach (Johnson and Rausser 1977). Walnut has been encompassed with a comprehensive reporting of management techniques (Funk 1966, Dillow and Hawker 1971, Dillow 1975). Furthermore, much informal information is available from individuals currently growing walnut, educators and researchers. Unfortunately, useful operating data for evaluating economic aspects of walnut growth responses is rather sparse. While literature is available on growth responses to many treatments, few studies have presented adequate economic data. Moreover, few plantations of sufficient age presently exist that have undergone management techniques currently recommended. Complex interactions vary responses of many treatments and hinder the estimation of parameters so necessary for the development of a complete silvicultural-economic model of walnut management systems.

In this paper we will present an examination of several black walnut management regimes. Earlier work (Callahan and Smith 1974, Garrett and Kurtz 1980) integrating the silvicultural and economic aspects of black walnut management have provided the building-blocks for this study.

WALNUT MANAGEMENT REGIMES

The development of a complete, single silvicultural-economic model is not possible at this time due to the lack of adequate data. However, separate models for different walnut management schemes have been developed, with each model containing a number of assumptions concerning recommended treatments and expected growth rates. For the purposes of this analysis, five regimes have been selected:

1) Walnut timber (veneer logs)
2) Timber and nuts
3) Timber, nuts and winter wheat
4) Timber, nuts, soybeans, winter wheat, fescue and grazing
5) Timber, nuts and grazing

Many other regimes exist; each landowner is limited only by land quality and his management preferences.

The schedule of activities for each regime and associated costs and revenues was subjected to an investment analysis using a

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financial return algorithm developed by Goforth and Mills (1975). Profitability indices are shown in the form of internal rate of return and present net worth. The algorithm also provides a sensitivity analysis for determining proportionate changes in present net worth and internal rate of return to changes in data inputs.

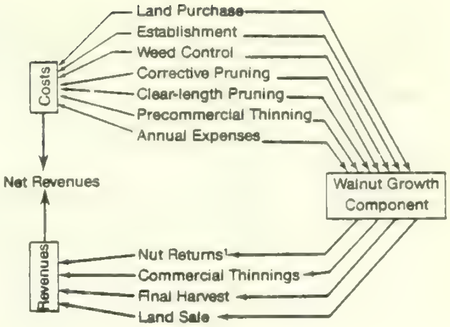
Each regime is analyzed for two different sites, medium quality (SI 65) and high quality (SI 80). The high quality site is assumed to be capable of a DBH growth rate of 1/2 inch per year, while the medium quality site is assumed to be capable of supporting a 1/3 inch per year growth rate. All regimes are carried to a rotation length of 60 years. This combination of options provides 10 different alternatives. Each analysis contains a series of assumptions about activity schedules, prices, yields, costs and benefits associated with walnut management (Table 1).

Walnut Timber

The walnut timber regime emphasizes walnut plantation management specifically for veneer logs (Figure 1). Trees are planted at a 12x12-foot spacing (300 trees per acre) to allow natural pruning and increase the potential for a straight central stem. Planting a large number of trees allows for selection gains since only 27 trees per acre will remain for final harvest. Trees are pruned to heights that allow a 16-foot log to be taken at harvest on excellent sites (SI 80). Prunings and thinnings are scheduled to yield maximum benefits, but also to minimize bole sprouting potential. Thinnings are scheduled to occur when the crown competition factor (CCF)[1] reaches 110. Each thinning will reduce CCF to 70.

Timber and Nuts

Management techniques in this regime are similar to the walnut timber regime, except pruning and thinning schedules are changed to provide a shorter log and a larger crown to benefit nut production. The ultimate objective involves a series of nut yields beginning in year 20 and lasting throughout the remainder of the rotation; final harvest yields a veneer log that is 10 to 14 feet in length (Figure 1).



[1] Nut returns would not contribute to the walnut timber regime.

Figure 1.--The relationship between cost and revenue activities associated with the walnut timber and nuts management regime.

Trees are planted at a spacing of 10x40 feet (108 trees per acre) allowing maximum crown development and some opportunity for selection gains. Again, following thinnings, 27 trees remain for final harvest. Thinnings occur when CCF reaches 90 and each thinning reduces CCF to 60. This CCF range, along with a reduction in pruning heights from the timber only regime, will allow maximum development of crown area.

Timber, Nuts and Winter Wheat

Multicropping management regimes include the same schedule of activities as the timber and nuts regime, plus additional agricultural activities (Figure 2). In this first multicropping regime, walnut trees are intercropped with winter wheat for the first 10 years of the enterprise. While it is possible that winter wheat could be produced longer than 10

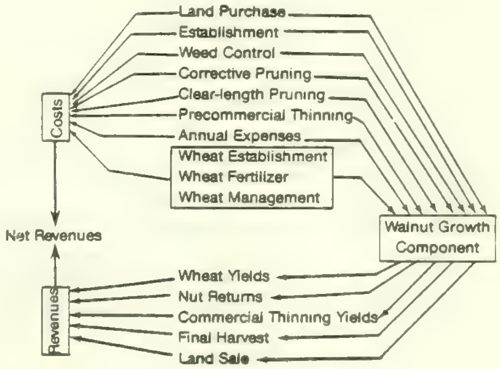


Figure 2.--The relationship between cost and revenue activities associated with the timber, nuts and wheat regime.

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[1] Crown competition factor is an index of competition between trees in a stand. It is expressed as a percentage of the ground area in the stand actually covered by tree crown area (Schlesinger and Funk 1977).

Table 1. Costs and revenues of walnut management by production categories.

Category	Description	Price per unit ($)
Land[1]	High quality (SI 80)	1000.00/ac
	Medium quality (SI 65)	800.00/ac
	Property taxes	2.50/ac/yr
Labor		6.00/hr
Trees	Establishment (equipment, manpower, stock)	1.25/tree
	Weed control (chemicals and application)	45.00/ac
	Corrective pruning (2 hrs/ac)	12.00/ac
	Management	4.00/ac/yr
	Pruning: 7 ft (5.0 hrs/ac)	30.00/ac
	9 ft (6.0 hrs/ac)	36.00/ac
	11 ft (6.8 hrs/ac)	40.80/ac
	7-11 ft (2.4 hrs/ac)	14.40/ac
	9-15 ft (3.1 hrs/ac)	18.60/ac
	11-17 ft (3.5 hrs/ac)	21.00/ac
	Precommercial thinning:[2] 2 inch DBH	4.86/sq ft
	3 inch DBH	3.30/sq ft
	4 inch DBH	2.31/sq ft
	5 inch DBH	1.89/sq ft
	6 inch DBH	1.47/sq ft
	7 inch DBH	1.23/sq ft
	8 inch DBH	1.95/sq ft
	9 inch DBH	.90/sq ft
	10 inch DBH	.81/sq ft
	Nuts	9.00/cwt
	Stumpage: 10 ft. log, 10.2" dibse	----
	10 ft. log, 13.8" dibse	40.00 ea
	10 ft. log, 17.0" dibse	226.00 ea
	10 ft. log, 19.8" dibse	370.00 ea
	14 ft. log, 8.9" dibse	----
	14 ft. log, 11.2" dibse	37.00 ea
	14 ft. log, 12.0" dibse	45.00 ea
	14 ft. log, 14.8" dibse	229.00 ea
	14 ft. log, 17.2" dibse	373.00 ea
	14 ft. log, 22.2" dibse	1009.00 ea
	14 ft. log, 25.9" dibse	1446.00 ea
	16 ft. log, 10.5" dibse	38.00 ea
	16 ft. log, 13.8" dibse	243.00 ea
	16 ft. log, 16.0" dibse	396.00 ea
	16 ft. log, 20.7" dibse	1089.00 ea
	16 ft. log, 24.2" dibse	1570.00 ea
Winter wheat	Establishment	31.50/ac
	Management	6.00/ac
	Fertilizer	33.50/ac
	Wheat	4.50/bu
Soybean	Establishment	39.50/ac
	Management	7.50/ac
	Fertilizer	32.00/ac
	Soybeans	11.50/bu
Fescue	Establishment	37.20/ac
	Management	7.50/ac
	Fertilizer	25.80/ac
	Seed	55.00/cwt
	Hay (deduct .15/bale when seed is removed)	.70/bale
Fencing	Perimeter fence: Establishment	42.00/ac
	Maintenance	1.25/ac/yr
	Electric fence: Establishment	49.00/ac
	Maintenance	1.15/ac/yr
	Removal	6.20/ac
Livestock	SI 65 feed costs (1-15 yrs)	26.80/ac
	SI 65 feed costs (16 yrs-rotation)	29.50/ac

SI 65 other costs[3] (1-15 yrs)	29.40/ac
SI 65 other costs[3] (16 yrs-rotation)	32.40/ac
SI 65 receipts (1-15 yrs)	77.60/ac
SI 65 receipts (16 yrs-rotation)	85.40/ac
SI 80 feed costs (1-15 years)	29.50/ac
SI 80 feed costs (16 yrs-rotation)	32.80/ac
SI 80 other costs[3] (1-15 yrs)	32.40/ac
SI 80 other costs[3] (16 yrs-rotation)	36.00/ac
SI 80 receipts (1-15 yrs)	85.40/ac
SI 80 receipts (16 yrs-rotation)	94.90/ac

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[1] Land sale price equals its purchase price to synthesize its holding cost.

[2] Precommercial costs are determined using unpublished data on file at the USDA Forest Service Forest Sciences Laboratory, Carbondale, IL. Cost is a function of hourly labor rate, DBH, and the number of trees removed. It is expressed as dollars per. sq. ft. of basal area removed.

[3] Other costs include veterinary and medicine costs, labor costs, utilities and machinery.

years due to the late spring leafing characteristic of black walnut, a conservative 10-year estimate is used because of the lack of supportive data. During this period, yields of winter wheat on the medium quality site (SI 65) are expected to be 10 percent less than on the high quality site (SI 80). Furthermore, establishment of agricultural crops under a multicropping regime with black walnut requires that approximately four feet of noncropped area be left on each side of the trees to facilitate management and reduce competition. This reduces usable agricultural land area by approximately 10 percent.

Timber, Nuts, Soybeans, Winter Wheat, Fescue, and Grazing

This most intensive multicropping, management regime (Figure 3) involves a schedule that includes many aspects of agriculture -- again, these agricultural activities are performed along with the timber and nuts activities. The proposed systems of multicropping are designed with the needs of each crop in mind.

Increasing shade with increasing age of the walnut will reduce soybean yields in years 6-10 by an estimated 20 percent below that expected for years 1-5. Soybean yields are also very sensitive to changes in site quality. Yields on a medium quality site (SI 65) are reduced to 75 to 80 percent of the yields on a high quality site (SI 80). Crop free rows are maintained for the walnut trees to grow with a minimum of competition. Therefore, usable land area is reduced by about 10-20 percent.

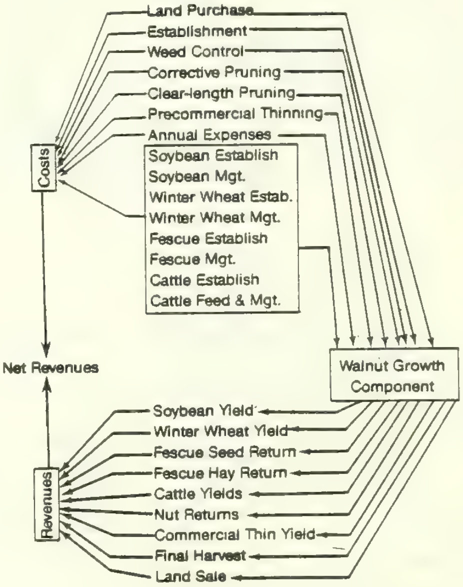

Figure 3.--The relationship between cost and revenue activities associated with the timber, nuts, soybeans, wheat, fescue and grazing regime.

After dual cropping soybean and winter wheat for 10 years, fescue is established in the areas between the rows of trees. Just as soybean and winter wheat are suitable intercrops with walnut, fescue also appears to be a suitable companion crop once the trees are old enough to have a well-established root system. Research has demonstrated increases in forage quality and quantity when grown in association with walnut (Smith 1942, Garrett and Kurtz 1981). Harvest of fescue seed and hay begins in year 11 and continues until year 15, when shade substantially reduces seed yields. Differences in site quality also result in a 10 percent yield reduction for fescue seed and hay on medium quality sites (SI 65) in comparison to high quality sites (SI 80).

Cattle grazing operations begin in year 16 when fescue seed yields become too low to add revenue to the enterprise. A perimeter fence must be constructed to contain the stock and will remain to the end of the rotation. Interior fencing is not required since, by year 16 or so, walnut trees should be large enough to withstand livestock damage. Techniques of grazing management commonly employed in Missouri are used throughout the rest of the rotation.

Timber, Nuts and Grazing

Grazing operations in this regime (Figure 4) are similar to those found in the intensive multicropping regime with the exception that grazing between rows begins soon after seedlings are established. This necessitates utilization of a tree protection fence system, as well as the perimeter fence. Protective interior fencing consists of an electrically charged wire that is suspended on stakes positioned six feet on either side of a row of trees. The interior fencing remains in place until the walnut trees are sufficiently large to minimize damage from grazing stock.

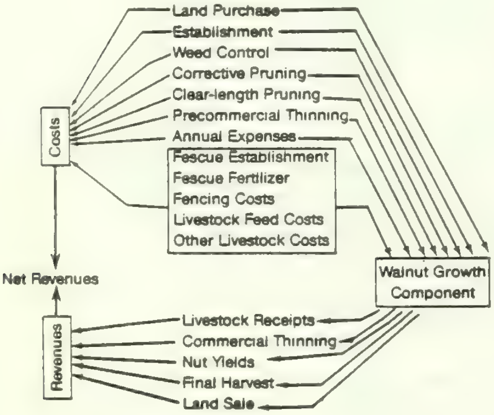

Figure 4.--The relationship between cost and revenue activities associated with the timber, nuts and grazing regime.

INVESTMENT ANALYSIS

Ranking of the five management options by internal rate of return and present net worth within identical site index and rotation age groupings is shown in Table 2. Internal rates of return for the "walnut timber only" regimes were the lowest of all regimes analyzed. This is largely due to the absence of early revenues from annual crops to help compensate for the high initial establishment costs. Establishment costs are very high for timber only regimes since 300 trees per acre are planted on a 12x12-foot spacing. Establishing 300 trees per acre and harvesting only 27 at rotation end provides an opportunity for selection gains to take place. However, the model used in this analysis did not consider increases in revenue other than those associated with an extra two feet of veneer log taken at commercial thinnings and final harvest.

Table 2.--Walnut management regimes ranked by internal rate of return (IRR) within groups of identical site indices (SI) and rotation ages (RA). Present net worth is given for each management regime.

Regimes	IRR (percent)	PNW (7.5%) (dollars)
SI 80, 1/2 inch GR, 60 RA		
Intensive multicropping[1]	15.91	1951.69
Timber, nuts, wheat	9.36	882.07
Timber and nuts	7.71	133.88
Timber, nuts, grazing	7.44	- 42.01
Walnut timber	6.68	- 575.28
SI 65, 1/3 inch GR, 60 RA		
Intensive multicropping[1]	13.00	778.62
Timber, nuts, wheat	7.76	65.16
Timber, nuts	5.92	- 559.47
Timber, nuts, grazing	5.52	- 765.17
Walnut timber	4.26	-1198.83

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[1] Intensive multicropping refers to timber, nuts, wheat, soybeans, fescue, and grazing regime.

Lower establishment costs and early revenues from collected nuts helped to increase the IRR of the timber and nuts regimes by about one percentage point above that observed for the walnut timber regimes. Logs taken at commercial thinnings and final harvest are shorter in length, but this allowed a larger crown to develop which increased nut yields. Nut yields are important, not only because of the additional revenue they contribute, but because of the timing of these contributions.

Internal rate of return can be raised 1.5 to 2.0 percent above that observed for the timber and nuts regime by adding a winter wheat management objective for the first 10 years of the enterprise. As with the addition of nut revenues, the additional revenues associated with wheat, and the timing of these revenues help to offset the high initial establishment costs.

The addition of grazing operations when establishing a timber and nuts regime provided very little benefit in terms of IRR. High fencing costs reduce the profitability of this regime. Grazing operations could be suspended until approximately year 16, thus eliminating the need for protective fencing due to the substantial size of the walnut trees.

Intensive multicropping is a useful practice in helping to offset high initial establishment costs that include high land prices paid for better sites. In most cases, the higher cost paid for high quality land is too extreme to be offset by added revenues from increased wood yields. However, this is not true in the timber, nuts, wheat, soybeans, fescue and grazing regimes. Here, added revenues from increased wood and crop yields more than offset the higher land price.

CONCLUSIONS

Growing black walnut either for wood products only, for both wood and nuts or in a multicropping management regime can be a profitable, as well as enjoyable, endeavor. Level of profitability is closely linked to intensity of management.

Quality of site also influences the level of profitability within respective management regimes. Obviously, the greatest influence of the higher site quality is apparent with the most intensive multicropping regime.

Multicropping management offers the greatest returns because of its more intensive use of land. While slight sacrifices might be made in agricultural crop yields and wood and nut production, the early returns from agricultural production offset the high initial cost of walnut establishment and permits substantial increases in profits.

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THE CHANGING STATUS OF PRIME AGRICULTURAL LAND:

FUTURE IMPLICATIONS[1]

Luther B. Hughes, Jr.[2]

Abstract.--Losses of prime agricultural land used for food production in the U.S. continues at an alarming rate. Losses of millions of acres of land to erosion, fuel and fiber crop production and conversion to non-agricultural use, i.e. urban development, highways, etc. occur annually. Conversion to non-agricultural uses alone exceed one million acres annually. Continued losses of this magnitude of food production potential has implications of changing the U.S. to a non-food exporting country, a serious blow to world hunger demand.

INTRODUCTION

World population is increasing at the rate of more than 180,000 persons per day (Brown, 1978). The resulting annual increase in world population is equivalent to more than one-third of the entire U.S. population. This population increase has caused concern about adequate food production, especially for the future. Thomas Malthus, in the early 1800's, projected that human population would increase geometrically and food production would only increase arithmetically. Although the United States is a notable exception, the Malthusian theory has been shown to be quite prophetic. This paper attempts to point out how the potential for food production in the future is being dangerously reduced, particularly in the U.S., by large losses of prime agricultural lands due to current land use practices and changes in land use.

Food production requires many inputs, including acceptable environmental and climatic conditions, available nutrients, proper control of pests including weeds and potentially productive soils or land. Barber (1976) discussed the importance of better nutrient efficiency and availability of nutrients for future food production. Hughes (1971) stressed the importance of proper pest control for maintaining high crop yields. However, with these inputs, the availability of highly productive soils is still necessary.

LOSSES IN PRIME AGRICULTURAL LAND

Significant losses of highly productive prime agricultural lands are matters of great concern. Trends in U.S. land use are shown in Table 1. Soil, relative to length of human life, is a non-renewable resource. Yet soils are often managed as if they are quickly regenerated.

Cropping Systems Alterations

Petroleum shortages in the 1970's brought additional new pressures for land use with suggestions of crop production for alternative fuel production. Alcohol production from grain crops, use of biomass and oils from crops may eventually prove economically feasible. As production of these "fuel crops" increases, a subsequent decrease in available acreages for food production follows. Projections of over 20 million acres for grain for alcohol production alone have been reported in the National Agricultural Land Study.

Similarly, if petroleum shortages continue, the manufacture of synthetic fibers may be jeopardized. Subsequent increases in fiber crop production may likely occur. The extent of food cropland "lost" will closely parallel the extent of fiber crop acreage increase.

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[1] Paper presented at the Walnut Council/ NNGA Symposium, West Lafayette, Indiana August 9-14, 1981.

[2] The author is Associate Professor, Agronomy Department, University of Missouri-Columbia.

Table 1.--Trends in Land Use. Includes United States, Puerto Rico, and Virgin Islands. Excludes Alaska.[1]

	1958	1977	Percent
	(Millions of Acres)		Changed
Cropland	448	413	- 8
Pastureland, native pasture, and rangeland	485	541	+12
Forest land	453	370	-18
Urban land (over 10 acres)	51	90	+76
Small areas of open water	7	9	+29
Other	60	77	+27
Total	1,504	1,500	

Accelerated Soil Erosion

The greatest pollutant of U.S. streams and rivers is soil. Most sediment originated as topsoil before detachment and removal by water. Few resources have been so badly managed or so quickly depleted. Soil is renewable only in geologic terms often requiring hundreds of years for an inch of soil development from bedrock. Conversion of land to more intensive crop use, i.e. pasture land or forest land to row cropland, often preceded accelerated erosion. One-third of the present U.S. cropland has already been lost by erosion (Pimentel, et al., 1976).

Natural processes of soil formation allow tolerable or permissible erosion to average 3-5 tons/ac/yr implying that soil formation at that rate allows no loss in productivity (Kohnke, 1969). However, soil erosion often far exceeds the "tolerable" limit. Average soil losses in excess of 10 tons per acre of cropland have been occurring in recent years in Tennessee, Mississippi, and Missouri while in the Corn Belt, cropland losses in Iowa have exceeded 9 tons/ac/yr. These soil losses can dramatically reduce productivity for the distant future. Losses of soil from the most productive lands also cause additional pressures to consider more intensive uses of more sloping marginal lands for producing food crops. Even more serious erosion may then result.

Conversion to Non-Agricultural Uses

Few losses in agricultural lands are so permanent as losses to non-agricultural uses. Demands for land for urban, transportation and water resource development uses exceed 3 million acres each year. In many instances, these demands have chosen the very best land, prime agricultural land. Prime agricultural lands were removed at the rate of one million acres per year from 1966 to 1975 according to the National Agricultural Land Study. In most instances, buildings, concrete, asphalt or water render this land permanently useless for agricultural production.

This loss is so serious that Florida, New Hampshire and Rhode Island will lose all their prime agricultural land within 20 years if the current loss rate continues. Many other states will lose over ten percent of their best crop producing lands (Fields, 1980).

POSSIBLE SOLUTIONS

National policy decisions will play a large role in determining whether food production will be adequate to meet U.S. needs of the future. Conversion of land to fuel and fiber crops will reduce land for food production. Economics and petroleum supply may dictate that decision process.

Accelerated soil erosion cannot continue at present rates without greatly reducing the soil's productivity. Advances in conservation tillage or reduced tillage methods will hopefully play a strong role in reducing erosion. Careful management of marginal lands will be necessary. Hupe (1981) reported that walnut production had a positive effect on forage production, especially fescue. Findings of this nature may help offset yield reductions due to erosion. If voluntary soil conservation efforts do not progress, legislative action may force stringent agricultural land use; action not likely to be well-received by many landowners.

Lastly, huge losses of prime agricultural lands to non-agricultural uses will necessitate immediate action. Table 2 shows agricultural land uses in 1977 in various regions of the U.S. while **in Table** 3 lands with potential for conversion to cropland are shown. However, continued losses of 3 million acres of land each year will be devastating to U.S. food production and must be reduced. As with soil conservation efforts, if losses of prime agricultural land continue, legislative restrictions on land use (zoning) will likely come to fruition.

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[1] "America's Soil and Water: Condition and Trends", USDA, Soil Conservation Service, December 1980.

Table 2.--Agricultural land uses in 1977 in selected census regions (millions of acres).[1]

Census Regions	Crop Land	Pasture Land	Range Land	Forest Land	Other Lands in Farms	Total
West	65.8	12.6	229.3	63.2	1.4	372.3
North Central	228.6	41.6	71.1	69.1	7.2	417.6
South	101.6	72.7	113.6	181.7	2.0	471.6
North-east	16.9	5.8	——	62.3	1.5	86.5
TOTALS	412.9	132.7	414.0	376.3	12.1	1,348.0*

*Excludes 10.9 million acres of "Farmsteads."

SUMMARY

Currently, the United States is a major food exporting country. New developments in using marginal land and in technology and plant breeding will likely allow higher yields per acre if other production factors remain constant. However, losses of prime agricultural lands to erosion, fuel and fiber production, and non-agricultural uses threaten our overall food production system. Efforts through research and conservation provide some promise for stemming these losses. Otherwise, Norman Berg, chief, USDA Soil Conservation Service, may well be correct in his statement: "Ten years from now, Americans could be as concerned over the loss of the nation's prime and important farm lands as they are today over shortages of oil and gasoline" (Fields, 1980).

Table 3.--Agricultural land with high and medium potential for being converted to cropland, by selected census regions and by 1977 land uses (millions of acres).[1]

	1977 Land Uses				
Census Region	Pasture land	Range land	Forest Land	Other	Total
West	4.0	14.2	1.1	0.3	19.6
North Central	18.8	12.5	7.0	2.0	40.3
South	26.6	12.2	20.6	0.7	60.1
North-east	1.9	———	2.2	0.5	4.6
Total	51.3	38.9	30.9	3.5	124.6*

*About 2 million acres of "Other Nonfarm" has potential for conversion to cropland.

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[1] "Agricultural Land Data Sheet, America's Land Base in 1977," National Agricultural Lands Study, Interim Report 2, 1980.

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A CASE STUDY OF BLACK WALNUT MANAGEMENT COSTS[1]

James E. Jones[2]

Abstract.--Intensive management is required to produce quality eastern black walnut trees. Weed control, fertilization and pruning are three important management practices for which the component costs are contained in this paper.

The culture of eastern black walnut (Juglans nigra L.) in a multicropping program requires intensive tree care. The tree must be cared for from its initial placement in the field to insure that weeds are controlled, soil fertility levels are adequate, and the desired tree shape is maintained.

Costs presented in this paper have been extracted from records maintained for Sho-Neff Plantation which is owned by Hammons Products Company of Stockton, Missouri. The project consists of 480 acres with 240 acres planted to trees. There is a total of 19,464 trees ranging in age from 3 to 7 years. Two thousand seven hundred and ninety are planted on a 40'x20' spacing with the remainder being on a 40'x10' spacing.

Sho-Neff Plantation is located in southwest Missouri near Stockton. The project is managed for the production of conventional agricultural crops, research, and demonstration within the multicropping framework. In Table 1 is presented costs for a one-time treatment of weed control, fertilization, and pruning.

CHEMICAL WEED CONTROL

Weed control on the project is carried out in several manners as conditions dictate. However, the only costs to be included here are for primary weed control or the application of chemicals during the spring.

Table 1.--Costs of primary weed control, fertilization and pruning in a large eastern black walnut plantation.

	Weed Control	Fertilization	Pruning
	----- (dollars per tree) -----		
Materials	$0.045	$0.063	---
Labor	0.013	0.038	$0.067
Equipment	0.024	0.004	0.004
Management	0.008	0.010	0.007
TOTAL COSTS	$0.090	$0.115	$0.078

Acceptable results have been obtained by applying a mixture of Roundup and Princep in a two and one-half foot band along each side of the row of trees. The chemicals are applied with a tractor mounted sprayer and side mounted boom. The boom is equipped with electric solenoids and no-drip nozzles to facilitate control and minimize application to crop areas.

The rate of application is 4 pints of Princep 4L and 3 pints of Roundup in a solution of 100 gallons of water. The equipment is calibrated to apply this mixture to one acre (8,712 feet of row length with a 2 1/2' band on each side).

Time used in application of the chemicals required 78 man hours and 51.7 hours on the tractor. The component costs of primary weed control are illustrated in Table 1.

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[1] Paper presented at the Walnut Council/NNGA Symposium, West Lafayette, Indiana, August 9-14, 1981.

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FERTILIZATION

Individual tree fertilization has been performed only one time since tree establishment. The application was made during late winter and early spring of 1980. A fertilizer blend (N-P-K) of 12-12-12 was surface applied within the dripline of all trees at the rate of 1 pound of product per inch of stem diameter.

The fertilizer was delivered to various drop points in 50 pound bags by tractors, then distributed by hand using buckets and calibrated containers. One hundred sixty-one (161) man hours were required to fertilize 19,464 trees with 15,470 pounds of fertilizer. See Table 1 for a complete presentation of fertilizer costs.

PRUNING

Pruning is necessary for most open-grown eastern black walnut trees. To date all pruning at Sho-Neff Plantation is done with hand pruners, lopping shears, and hand saws.

Pruning is done primarily in February, March and early April. The pruning program includes both the conventional pruning and tip pruning. Consequently, the time element is greater than would normally be experienced for trees in this age and size class. However, some trees, due to their size and condition, will no longer be tip pruned.

During the winter and spring of 1981 all trees were individually inspected and treated. The time involved was 244.5 hours. Table 1 illustrates additional costs.

SUMMARY

Producing quality eastern black walnut trees requires intensive management. It is well established that weed control and pruning are essential with the jury still out on fertilization. However, from the standpoint of multiple crops, it is possible that we can justify the additional expense to maintain the plant in a high state of vigor.

There is a definite cost advantage to the operation of a large planting. For small plantings which are widely separated and operated from a central location the costs could easily double.

BLACK WALNUT MANAGEMENT COSTS: RESULTS OF THE 1981 SURVEY[1]

Timothy D. Marty and William B. Kurtz[2]

Abstract.--Costs are described for various cultural practices related to the management of black walnut. Average costs were obtained from a survey of Walnut Council members to which 91 growers responded. A cash flow for a "typical" walnut plantation was synthesized from the average costs and timing of practices reported in the survey. Our analysis indicates that a modest internal rate of return of 6.64 percent could be realized on all costs made prior to the time of investment maturity. The present net worth of the cash flow would be $519.18 per acre, discounted at a 5-percent interest rate.

Black walnut management involves many decisions within the constraints of the resource base and subject to the motivations and objectives of the individual grower. These decisions affect the amount and timing of costs and revenues and resulting profitability of the program. During the summer of 1980 a mail survey was conducted with members of the Walnut Council to further define some of the costs of walnut management. Results are reported in Kincaid and Kurtz (1981).

In the summer of 1981, a similar questionnaire was mailed to Walnut Council members seeking cost information on their walnut growing operations. Ninety-one growers responded. Many of the returned questionnaires had unanswered questions where treatments had not been applied, or costs were unknown. The cumulative usable response, however, offers some insight into black walnut management as it is being practiced by members of the Council.

MANAGEMENT CONSIDERATIONS

Responses to the 1981 survey were coded into 50 separate variables. These fall into four categories giving information on the respondents, land and timber resources, costs and revenues.

Management Objectives and Motivations

Walnut grower characterization is based on management objective and motivation. Of the respondents, 45 percent named timber production as their primary objective, 27.5 percent cited timber and nut production, resource preservation was valued highest by 11 percent, and the remaining 16.5 percent selected multicropping or a combination of objectives. Responses to the question of management motivation were divided almost evenly between three major categories; personal satisfaction (26.4%), financial return from timber and/or nuts (23.1%) and long-term investment or speculation (22.0%). This would indicate that while a large percentage of growers manage for timber or timber and nuts, less than one-quarter do so for financial return. Financial profitability does not appear to be a dominant motivating factor in walnut management for many growers.

Resource Base

The resource base is comprised of variables representing stand area and age, and land value and quality (Table 1). Areas of walnut stands generally appear to be small. More than half of the respondents have 10 acres or less of planted walnut and 90 percent have 50 acres or less. Similarily, nearly three-fourths have less than 10 acres of naturally occurring walnut stands, with 20 percent indicating no natural stands.

Most walnut stands are also relatively young. Plantation age is less than 10 years on 81 percent of the land, with over half being less than 5-years-old. Natural stand age is a

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[1] Paper presented at the Walnut Council/ NNGA Symposium, West Lafayette, Indiana, August 9-14, 1981.

[2] The authors are graduate research assistant and professor, respectively, School of Forestry, Fisheries and Wildlife, University of Missouri-Columbia.

Table 1.--Summary of black walnut management data, 1981 survey of black walnut growers.[1]

Category	Units	Responses (number)	Mean	Standard deviation	Range
Acres planted	acres	85	19.25	27.11	0.0 - 137.0
Acres natural	acres	69	13.54	20.22	0.0 - 85.0
Site index	feet/50 years	10	67.70	8.54	55 - 88
Land purchase price	$/acre	74	375.11	358.58	14.0 - 2000.0
Land current value	$/acre	74	1497.97	1172.91	300.0 - 6500.0
Number of trees	trees/acre	76	458.82	686.30	27.0 - 4840.0
Stock cost	$/tree	64	0.28	0.89	0.0 - 7.0
Site prep cost	$/acre	62	27.06	67.70	0.0 - 400.0
Planting cost	$/acre	56	45.48	87.60	0.0 - 500.0
Weed control	$/acre	44	21.91	28.28	0.0 - 125.0
Corrective pruning	$/acre	16	15.01	16.51	0.0 - 50.0
Corrective pruning	$/tree	--	---	---	-----
Height pruned	feet	33	10.94	5.09	3.0 - 23.0
Age pruned	years	28	12.53	8.34	2.0 - 40.0
Pruning cost	$/acre	9	48.11	55.70	0.0 - 150.0
Thinning cost	$/acre	6	32.00	25.81	5.0 - 80.0
Annual tax	$/acre/year	49	6.81	10.06	0.0 - 50.0
Management cost	$/acre	19	20.61	26.90	0.0 - 100.0
Hourly labor wage	$/hour	16	4.19	1.64	0.0 - 8.0

[1] Respondents to May, 1981 survey.

little more evenly distributed, but still only 28 percent of the stands are older than 10 years.

Only 10 respondents knew the site index[1] of their land (mean value 67.7) so the descriptive estimation of land quality provides a better estimate of the type of land being used to grow walnut. Landowners rated their land as excellent (27%), good (55%), fair (16.9%) and poor (1.1%). Most of the respondents indicated their land was used as pasture or crops before walnut production (79%), with only 19 percent indicating woods as a predecessor to walnut. Two questionnaires were returned by people growing walnut on land formerly mined.

Land purchase price varied widely from $14 to $2000 per acre, with an average value of $375. Price variation is largely attributable to time of purchase (1916-1980); over one-half of the respondents indicated their land had been purchased since 1970. Current land value was estimated at about $1500 per acre, with the most frequent response being $1000 per acre. Weighted mean land value was not calculated.

Management Costs

Costs associated with black walnut operations are incurred at many different times in the course of a rotation. Cost variables included in the questionnaire can be grouped into the general areas of site preparation, planting and establishment, weed control, pruning, thinning costs and annual taxes.

Site preparation

No dominant method of site preparation is apparent. One-fourth of the respondents used no site preparation at all, one-fourth used plow and disc, and the remainder used mowing, chemicals or some combination of these methods. Some 45 percent of the owners listed no site preparation cost, apparently either choosing to not place a cost on their labor, or only a small percentage of their land required preparation due to prior management practices (i.e., pasture/crop). Of those who did list a cost, the average value was $27 per acre.

Planting

Planting was most frequently done with a spade (38%), bar (18%), machine (15%) or auger (15%). Over 90 percent of the respondents planted seedlings. Average seedling cost was $0.25 per tree, although a large number of individuals indicated they had received free seedlings. Average planting cost was about $45 per acre. No correlation could be found between planting cost and planting method. Planting was done at an average of 458 trees per acre, approximately a 10-foot x 10-foot spacing. Only 15 percent of the planting was contracted out, the remainder (85%) was done by the landowners at an average time of 15 hours per acre.

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[1] Site index represents the average height (feet) a tree will grow in 50 years.

Weed control

Weed control most often involved some combination of mowing and chemicals (49%). This was accomplished at a cost of about $22 per acre. When chemicals were used, they were usually spot applied at an average diameter of about 3 feet.

Pruning and thinning

It is difficult to draw conclusions relative to corrective pruning because of the low response rate. Landowners appear to either not have practiced or lack adequate records of these silvicultural treatments. Corrective pruning usually takes place at ages three and four years. The cost of corrective pruning averaged about $15 per acre, and about 9 hours of labor per acre were required. Cost is low in relation to the labor requirement because over one-third of those answering the question assigned no cost to their corrective pruning, apparently counting their own labor as zero. Pruning is generally done at the age of 12 years, to a height of 11 feet, at an average cost of about $48 per acre. Thinning was indicated by only seven landowners at an average age of 19 years and cost of $32 per acre. It is likely that because of the young age of many of the stands, as noted earlier, no thinning has been needed thus far.

Taxes and management

Two additional costs included in the survey were annual tax and management. Averages are $6.80 per acre for annual tax and $20 per acre for the management cost. Most landowners reported paying less than $5.00 per acre annual tax, but several respondents indicated paying in excess of $20.00 per acre which inflated the average value. Further refinement is needed in the questionnaire to more accurately determine these costs. Future questionnaires will list the specific items to be included as management costs.

ECONOMIC MODEL

An economic model was developed based on the cash flows described in the preceding section. This model represents a "typical" acre under black walnut management for veneer production utilizing the timing and dollar magnitude of the various management practices observed from the survey results. In order to preserve consistency within the model, land purchase and holding costs, annual taxes and management costs have not been included. The categories of practices in the model and their respective costs and times of application are shown in Table 2.

Table 2.--Black walnut management cash flow.

Category	Year(s) incurred	Cost
		($ per acre)
Site preparation	0	27.00
Planting stock	0	126.00
Planting	0	45.50
Initial weed control	0	22.00
Weed control	1-3	22.00
Corrective pruning	3-4	15.00
Pruning (10 feet)	10	48.00
Pre-commercial thinning	15	50.00
Pruning (17 feet)	16	48.00
Thinning	30	0.00
Thinning	40	0.00

Category	Year	Revenue
		($ per acre)
Thinning	48	520.00
Final harvest	60	6102.00

Our "typical" one acre stand is located on a low- to moderate-quality site capable of sustaining a one-third inch per year growth rate. To obtain veneer quality material over the course of the rotation, a 60-year length was assumed. Initial costs include site preparation ($27/acre), planting stock (450 seedlings @ $.25/seedling), planting ($45.50/acre) and initial weed control ($22/acre). Additional weed control would be administered in years one through three at a cost of $22 per acre. In years three and four corrective prunings would cost $15 per acre. Two prunings are planned at age 10 to a height of 10 feet, and at age 16 to a height of 17 feet.

A precommercial thinning at age 15 costs $50 per acre (225 trees removed @ $.22 per tree). Two self-supporting thinnings are planned for years 30 and 40. In these operations the revenue received from the sale of removed material is presumed to offset the cost of thinning. Seventy-five trees are removed in year 30 and 110 trees in year 40.

A commercial thinning of 13 trees occurs in year 48, returning $520. These trees should average just over 16 inches dbh and contain 60 bd. ft. per stem. A current average stumpage price of $.67 per board foot was used to calculate the value of this thinning material. Final harvest of 27 trees at rotation end in year 60 produces $6,102 in revenue. It is anticipated that these trees will average 20 inches dbh and yield around 100 bd. ft. per tree. A current average stumpage price of $2.13 per bd. ft. was used to calculate the value of the material removed during the final harvest. All revenues were inflated at a 1.5 percent annual rate to arrive at the future value of stumpage produced. This figure, based on observable trends within the walnut stumpage market, represents the average annual price increase over and above all other costs and returns (Hoover 1978).

It should be noted that no revenues from nut production were included in the model. However, as shown by Garrett and Kurtz (1981), substantial increases in profitability can accrue to a walnut producing enterprise by including nut production in the management scheme.

The internal rate of return (IRR) yielded by this "typical" plantation was 6.64 percent. This represents the average interest rate earned on all costs prior to the time of investment maturity at the end of the rotation. Present net worth (PNW) of the investment computed at a 5 percent interest rate was $519.18 per acre. This is the net value of all costs and revenues discounted back to the present time at a 5 percent interest rate. Obviously if land costs exceed $500 per acre the investment, as structured here, will not yield a 5 percent return. This finding is consistent with returns to the "basic" black walnut enterprise model developed by Callahan and Smith (1974).

CONCLUSIONS

Investment in black walnut as structured for our "typical" plantation yields modest returns. Our analysis does show that walnut is being managed in a profitable fashion. Treatment costs involve only a very small portion (less than 10%) of all costs of the walnut enterprise. These expenditures yield substantial benefits through increased size and higher quality material at harvest.

Increased returns to black walnut management can be achieved from various factors not specifically addressed in this analysis. Management for nut production and/or the adoption of a multicropping management scheme both have the potential for enhancing the profitability of the basic wood producing enterprise.

Obviously, the plantation as constructed is "typical" only in the sense that it represents an average based on the various management experiences of a group of walnut growers. It should be kept firmly in mind that the sample group has widely divergent management objectives and motivations as well as different socioeconomic characteristics. Nonetheless, this should not deter from the usefulness of our analysis in describing the responses to the 1981 survey. The relationships of the treatment cost averages we have presented are important, not only to each other but also to the overall enterprise. Black walnut growers must be familiar with their treatment costs as a matter of good business practice.

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A CRITICAL LOOK AT THE EXPECTED RETURN ON INVESTMENT FROM PLANTING BLACK WALNUT SEEDLINGS[1]

By Dwight R. McCurdy[2]

Before investing money, time, and land in planting black walnut seedlings several factors should be considered by anyone placing a positive value on their money. First, a person should realize any money spent purchasing, planting, and caring for walnut seedlings has a greater cost than the out-of-pocket expenditures for the seedlings. To illustrate, if $100 are to be spent in purchasing and planting seedlings, the owner before making the investment has at least two alternatives:
(1) putting the $100 in a coffee can and burying it, and (2) placing the money in a relatively risk free federally insured savings account. Assuming 40 years passes, the amount in the coffee can (assuming it can be found) will still be $100. However, the money in the savings account would be $1,498 if the bank paid seven percent compounded annually. To be completely accurate, the investor would only have $1,048.60 after taxes if he was in the 30 percent income tax bracket. Therefore, the person planting the walnut seedlings should have at least $1,048.60 after selling the trees and after taxes (assuming no other costs). The actual amount the walnut investor will receive from his investment will depend on many factors--some of which are listed below:

1. The amount of money for which walnut trees can be sold at maturity;
2. The additional monetary costs and returns resulting from growing the walnut trees;
3. Other costs and returns (externalities) that result to the investor from growing walnut trees;
4. The opportunity for additional investment alternatives; and
5. The risks and uncertainties involved in growing walnut trees.

Table I contains the estimated costs and returns per acre for an hypothetical walnut investment. This "basic model" of a black walnut plantation was developed by Callahan and Smith in 1974. It should be recognized these costs and returns were developed for a specific site and were based on several assumptions. For example, sites vary in suitability for walnut timber production. The rate the trees grow and the survival rate for individual trees will vary between sites. These two assumptions are major factors affecting the profitability of the investment. Therefore, as a minimum a forester should conduct a site analysis to determine the expected growth and survival rates relative to the appropriate silviculture treatments needed for walnut timber production.

In critically analyzing the applicability of Callahan's basic model (for an hypothetical walnut investment) for other walnut investment opportunities we will first discuss Item One, Table I, land cost. It is well accepted that land values vary widely thereby making generalizations about the return on investment from a given site suspect. However, it is recommended that land values not be included in walnut investment analyses. Land in itself is an investment and appreciates in value regardless of use as long as its character isn't degraded. This appreciation in land value may be at a faster rate than the returns from the land's use thereby making the combined investments of land and land use appear better than the investment in land use alone. It should be pointed out this situation is nearly 100 percent valid relative to forest production investments. For example, land values may increase at a rate of 10 percent compounded annually in comparison to less than 5 percent obtained from monies invested specifically in timber production. One negative aspect of leaving out land costs (or value) is that holding or opportunity costs of the land over the investment period are not accounted for in the analysis.

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[1] Paper presented at Walnut Council Annual Meeting, Purdue University, West Lafayette, Indiana, August 13, 1981.

[2] Professor of Forest Economics, Department of Forestry, Southern Illinois University, Carbondale, Illinois.

The second expense item in Table I contains the initial establishment costs other than seedling and planting expenses. These expenses could vary from nothing to a relatively large amount depending on the condition of the land. For example, fencing to prevent grazing by cattle may be necessary.

The third expense item, cost of the planting stock, is a critical item since it depends on the spacing between seedlings and in turn spacing dictates the number of seedlings per acre. Spacing also affects (1) the silvicultural treatment costs, (2) expected growth rates, and (3) quality of the harvested stem. For example, spacing may vary from 10 x 10 feet (435 trees per acre) to 40 x 40 feet (27 trees per acre).

The fourth expense item, planting costs, can also vary widely between investment opportunities. For example, one site may be suitable for machine planting with no site preparation expenses while at the other extreme another site may require hand planting and then only after bulldozing a residual stand of undesirable trees.

The next seven expense items are specified by a given silvicultural prescription which should vary with site conditions. As mentioned earlier, a forester should be consulted to determine the alternative silvicultural treatments that will be needed for the specific site being considered. For example, Callahan selected his hypothetical treatments from the following alternatives:

Method 1. Completely disk the planting area and control subsequent weed growth by the application of chemicals.

Method 2. Completely disk the planting area and control subsequent weed growth by cultivation.

Method 3. Completely disk the planting area and limit subsequent weed control to spots or strips around the planted tree with weeds between treated areas controlled by mechanical means such as mowing or cultivation.

Method 4. Completely disk the planting area and limit subsequent weed control to spot weed control around individual trees using chemicals.

Not only should the silvicultural prescriptions vary between sites (investment situations), the costs of accomplishing a specific task such as pruning will differ between investors. For example, one landowner may already own the equipment needed and he might also have the skill to perform the tasks, while on the other hand, another investor may be required to hire the complete performance of the task. More specifically, one person may own "old" equipment resulting in a small capital investment while a second person may have "new" equipment with a comparatively higher capital investment but lower operation costs.

A more important consideration when calculating the expected expenses is the fact most expenses occur in the future requiring the investor to be a futurist. The model as presented by Callahan specified no increase in silviculture treatment costs for like tasks thereby assuming that today's expenses will remain parallel to inflation in amount. However, recent history has demonstrated silvicultural treatment expenses increase at a greater rate than inflation.

Expense item 12, administrative costs such as taxes, insurance, etc., which occur annually seem relatively small but when accumulated, these expenses result in a large proportion of the total. In fact, a small variation in the amount of administrative expenses can significantly effect the profitability of the investment.

The final expense item in Callahan's basic model, self-supporting thinning, was placed at zero costs under the assumption it should be done with revenues from fence posts. Here again, if there is no market for fence posts, firewood, etc., the profitability of the investment is greatly reduced. Furthermore, if proper thinnings are not performed the length of time to final harvest is significantly lengthened. The time period between planting and final harvest is one of the major elements in determining the size of the return on the investment.

On the other side of the ledger are the revenues generated from the walnut investment. The amount of revenues is dependent to a great extent on the quantity and quality of timber available for thinning and harvest. But, as mentioned earlier, timber availability is in turn dependent on site conditions, spacing, silvicultural treatments and environmental conditions (climatic, disease, insect, etc.) over the life of the treatment. All these can vary dramatically for different investment opportunities. For example, survival of planted seedlings to maturity can vary from less than 10 percent to over 80 percent. Also, the volume per acre at 50 years can vary between 2,000 and 16,000 board feet depending on the site and original spacing.

Also, similar to expenses, most, if not all, revenues occur in the future thereby making realistic estimates difficult. For example, the price received from the walnut timber varies significantly with the following:

1. The form in which the timber is sold; such as (1) on the stump, (2) as logs at the logging site, or (3) as logs delivered to the buyer;
2. The market conditions at the time of the sale. The timber industry is very cyclic relative to prices since the demand is derived from the demand for a finished product of much greater relative value; and
3. The product into which the timber will be processed; such as lumber versus veneer. Veneer walnut is the only product having sufficient value to even consider possible investment. If an export market is available the chance to receive favorable veneer prices is also enhanced since export prices generally are much higher than domestic prices.

In Callahan's basic model, prices were assumed to remain parallel to inflation as indicated by using 1974 prices. However, unlike expenses, prices over the recent past have paralleled inflation. For example, average walnut prices in Illinois between 1967 and 1976 increased 83 percent and the wholesale price index also increased 83 percent (McCurdy, 1977).

When determining the return on investment, the present or discounted value of all expenses must be equalled with the present value of all revenues (Column 5, Table I). The discount or interest rate that results in expenses equalling revenues is the rate of return on investment. For Callahan's basic model, with land values being eliminated, the rate of return was 6.5 percent.

It is this 6.5 percent that the investor should compare with his alternative opportunities such as placing his money in a can, savings account, etc. However, to be rational the following adjustments must be made to the return on investments being compared:

1. All returns should be after taxes have been deducted. Forestry, because of capital gains, has an advantage relative to land uses returning annual revenues.
2. The rate of returns should be adjusted for risk and uncertainty. For example, the probability of not receiving the estimated future revenues is generally greater with forest investments in comparison with most other land use investments.
3. The externalities from the investments should be compared. For example, forest investments often enhance the recreation values received from a tract of land.
4. If the investment is to be continued by heirs, what is the probability they will have the same time preference for their money as the original investor and an identical interest in forestry or natural resources. The rate of change in land ownership on the average indicates the above probability is very small.

CONCLUSION

When analyzing the potential return on investment from black walnut timber production, site and time specific estimates are needed relative to the expected costs and returns. Generalizations from data published from other sites and ownership conditions can lead to significant differences. In most cases, the assistance of a consulting forester is advised.

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Table 1. Basic Model of a Black Walnut Plantation Investment, Per Acre.

Item Number	Item	Year of Occurrence	Actual Value (Dollars)	Present Value (6.5% Discount Rate)
EXPENSES:				
1.	Land	0	350	N.A.
2.	Initial Establishment	0	70	70
3.	Planting Stock	0	30	30
4.	Planting	0	25	25
5.	Weed Control (Cultivation & Chemical)	0	35	35
6.	Weed Control (Chemical)	2	15	13
	Corrective Pruning		10	8
7.	Weed Control (Chemical)	3	15	12
	Corrective Pruning		10	8
8.	Weed Control (Chemical)	4	15	11
	Corrective Pruning		10	7
9.	Pruning to 8 feet	8	90	54
10.	Pruning-50 select t.p.a.	13	50	22
11.	Thinning	15	0	--
12.	Annual Charges	1-50	10	144
				439
REVENUES:				
13.	Thinning	25	50	10
14.	Thinning	35	200	22
15.	Final Harvest	50	9500	407
16.	Terminal Land Value	50	350	N.A.
				439

Source: Callahan and Smith, 1974.

WALNUT RESOURCE: AVAILABILITY AND UTILIZATION

Presented at the NNGA/Walnut Council Joint Meeting
Purdue University, West Lafayette, Indiana, August 13, 1981

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Fine Hardwoods/American Walnut Association
Indianapolis, Indiana

Abstract -- Walnut Resource: Availability and Utilization

High quality black walnut trees for lumber, veneer, and gunstocks are still in a somewhat short supply. The outlook for their demand is excellent. Current hardwood forestry programs need to reach more landowners; and hardwood forestry education must become more effective to insure adequate supplies of these valuable raw materials for the future. Utilization of the entire tree is likely to continue to become a reality as the use of wood as an energy source increases.

When you ask a member of the industry today about the walnut resource, he is likely to tell you "good walnut trees, or for that matter, good trees of any species, are hard to find."

In 1966 at the Walnut Workshop in Carbondale, Illinois, Steve Boyce started his speech with a statement "large diameter, high quality veneer and sawlogs - these are the walnut timber products in critical shortage." In the abstract written for a paper presented at the 1973 Black Walnut Symposium, Jim Blythe said, "rising prices with fluctuating demand indicate a scarcity of high quality walnut, a need for more efficient and complete utilization of the walnut resource, and the necessity for reducing costs in domestic manufacturing of walnut products so they can remain competitive with substitutes and foreign products."

Here we are, not quite ten years later, and we still have most of the same problems. The buyer of walnut timber, for nearly twenty years has had to buy trees that are smaller in both diameter and in total height. He has had to buy trees with more pin knots, frost cracks, spiral grain, and other factors that reduce the yield from the logs. At the same time competition for the raw material has forced the cost of logs to skyrocket upwards.

The demand for black walnut has helped motivate timber management by allowing for more profit on the part of the landowner, and the industry recognizes the necessity of landowner profits and knows it can and should result in more management. Unfortunately, all too often the landowner, or his or her heirs immediately sold the timber and failed to return any of this money back into a forest management program. Often with heirs, it is strictly a case of raping the land for whatever dollar value they can derive.

As we look into the future, we feel that walnut will continue to be readily available, but the quality problems will continue. The challenge to foresters and landowners is almost frightening. Somehow, we have to motivate the people who own the land growing hardwood timber to do a much better job of managing the trees. For nearly a hundred years we have heard the cries from the wilderness that we are going to run out of timber and that some species will become extinct. We know this can happen, but we also know there are tremendous opportunities to make sure that this does not happen.

In his report to the Indiana State Board of Agriculture for year 1880, Professor C. I. Ingersoll of Purdue University indicated that about 85% of the black walnut resource in the State of Indiana had been disposed of. Professor Ingersoll warned the people of Indiana not to destroy their forests. To quote him, "if the cornfield is destroyed, it can be restored in a single season, but when the forest is destroyed, a hundred years are required for its full restoration." To continue from Professor Ingersoll, he stated "go with me if you please to some of the countries of Europe and Asia, and read there the silent admonishments stamped by the absence of woodlands for centuries."

The lessons are well documented, unfortunately only a few eyes have seen them. It is time in America, particularly here in the midwest, when we stand up and admit that we are not doing the job in hardwood forestry. We can kid ourselves and we can say that we are growing more timber than what we are using. We can justify reasons for land clearing. We can bow down to the interests of corn, soybeans, and other row and pasture crops. We can excuse the utility right-of ways, and the home builders and the real estate people for taking our tracts of timber and making them into the finest, most expensive homes in the area. We can come up with many excuses, but if you are satellited with the responsibility of finding timber to operate a mill Monday through Friday, then you know from your own experience and in your own heart that the course we are on today will not lead us to a land of plenty.

As we sit in meetings, we hear how the wilderness and preservation people are demanding that more acres each year be locked up, never to be managed again for multiple-use purposes. Those of us in the timber business and many of you in the forestry profession, for the most part, do not go along with these theories. Yet, we sit in these same meetings and often do not speak up, and we do not move forward with programs of our own. We seem to always be defending our actions. If the preservation groups continue to insist on having single - purpose management areas set aside, then we probably should demand that single-purpose areas be set aside for timber production and timber production only. It has been said many times that the best defense is a good offense. We have got to get busy, if we are going to remain in this ball game at all.

Fortunately, it is not too late. There is still time to turn hardwood forest management in America around, but I challenge all the landowners, all the industry, all the individuals working in this field to stop fooling around and get down to the business at hand of practicing those forest management techniques which are already known. The day may come, heaven forbid, when we will have to legislate the practices that we know have to be incorporated if we are going to continue to have adequate timber supplies in America.

The other part of my assignment is to talk about utilization. I believe that we have come a long way in America, particularly in the softwoods and we are doing quite well in the hardwoods, at using almost the entire tree.

At the mill level, the progress is apparent. You rarely see the piles of bark and sawdust. In most cases you do not see the scrap that was once taken to the backside of the mill and bulldozed over the hill. We are now using the bark for landscape and mulch, if we are not burning it along with the sawdust and the other edges and trimmings as an energy source for the mill. We are working harder to find markets for all grades of hardwood lumber and veneer. At the Association level, we have for many years been involved in a character marked program to promote the use of all the grades that are developed in the manufacturing process.

In the woods we still have work to do. It is true that we find a lot of tops, limbs, and unmerchantable trees still left in the woods. This material will in time be used. We are currently seeing interest for fuelwood. I believe the day will come when the industry will have a crew to chip this material and take it back to the mill to add to the energy source. We should all be thankful for the research currently underway in this area.

To the growers of the resource I can say that the outlook is good. Raw material prices have taken only one direction in recent years, and that has been upward. Granted it has cycles, but the general trend is upward and I do not see how it can go any way other than up from now on, which is good news for you because you can make forest management investments with the confidence of a good return on your investment.

Whether the industry can keep up with the money market and the high prime rate is questionable. Whether or not anyone can keep up with the prime rate is questionable. This is one of the most serious problems facing the industry. With the high prime rate and the business slow, demand for timber is likely to soften slightly. So it is to your advantage to see the prime come down. Hopefully, at the same time inflation will be lowered, and this country will return to a somewhat stable and normal economic situation again.

I am optimistic that the future for hardwood lumber and veneer is excellent. We all know that the children of the population explosion that occurred in the late 1940's have now moved into the prime buying age bracket. They will be buying homes and they will be filling those homes with furniture, which means more demand for your timber products. With all other factors being normal, we expect excellent business throughout the 1980's. By the time the war babies move on to an older age bracket, where they may not buy so much, we will be more into a worldwide market, which again will brighten the prospects and opportunities for the timber growers of the midwest.

BUYERS PERSPECTIVE ON MARKETING WALNUT TREES

Presented at the NNGA/Walnut Council Joint Meeting
Purdue University, West Lafayette, Indiana, August 13, 1981

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Abstract -- Buyers Perspective on Marketing Walnut Trees

Marketing walnut timber is a business transaction between a willing buyer and a willing seller. The value the seller receives is the approximate difference between the end value of products produced from the tree/log mix involved in the sale and all related costs and profit. The stumpage value is determined by a buyer who estimates value based upon evaluation of location, size, and defects.

After a sale, trees are cut, bucked into logs and transported to a mill for processing or re-sale. The movement from landowner to mill may take several routes:

Landowner → Independent buyer → Company buyer → Mill

Landowner → Company buyer → Mill

Landowner or Independent buyer → Mill

Timber sales are transacted in many ways, but in all cases the timber buyer pays for a given number of trees. The most common selling methods are:

1) Lump Sum Sale--On a given piece of land the buyer pays for all usable timber within given agreed upon constraints, eg. All walnut over 16 inches, all merchantible red oak, and hackberry over 14 inches.

2) Sealed Bids--This method is essentially the same as a lump sum sale, except sealed bids are submitted by buyers. Bids are opened by the seller at a given place and time.

3) Percentage--An agreement between the landowner and buyer: the buyer cuts the trees and then sells to one or more company buyers. The buyer and seller divide proceeds based upon predetermined percentage of gross receipts.

4) Dollars Per Tree--The seller sets a dollar value per tree standard which the buyer must meet, eg. The timber sale must average \$100 per tree. The buyer must then pay on the basis of \$100 per tree cut (poor practice, leads to high grading).

5) Grade and Yield--The buyer cuts, bucks, scales and grades logs. The price paid to the seller equals the scaled volume by grade times the agreed upon price per grade.

6) Dollars Per MBF--The buyer cuts, bucks and scales logs. Payment is based on agreed upon price per thousand board foot. The seller and/or third party may assist in scaling logs.

7) Auction--The buyers are given an opportunity to review marked trees or the sale area, and at a given time and place an auction is held (rarely done).

8) Telephone Auction--The seller calls prospective buyers and tries to manipulate bid prices by playing buyers against each other on an individual basis. This is a common practice after the seller has accepted original bids (sealed or otherwise). Often the bids quoted in the "auction" are inaccurate.

STUMPAGE VALUE

VALUE EQUALS WHAT SOMEONE WILL PAY. No walnut buyer (at least for very long) can consistently invest more in a purchase than he receives in return. All values are based, in the final analysis, upon the market value(s) of products produced by the mill. This market value(s) minus all transportation, processing, and merchandizing costs plus a reasonable profit establishes a given average log value. This is the competitive log value paid for a given log delivered to a mill. This value minus a cutting and hauling charge, minus transportation fees (truck or rail), minus buyers expense/profit equals the stumpage value.

The stumpage value of walnut trees is a factor of volume (board feet), grade and value per board foot per grade.

The value of lumber logs is based upon size (diameter and length), quality and often general area of origin. All three factors relate back to the kind and quality of product produced. The higher the quality (end value) the greater its value to the mill. For example, larger is better than smaller, cleaner straight is better than defective crooked, and northern is better than southern.. Hence, a large, clean, straight northern log is worth much more than a small, defective, crooked southern log.

The value of veneer logs is likewise a factor of size (diameter and length), defects, area of origin (general and specific) and a rather undefinable buyer evaluation of wood quality (color, grain, pattern, etc.). I do not know of any veneer log grading system that can be applied to the value of veneer logs. For example, I commonly pay 3 times more for one log than another even though both would fall within the same general log grade. This differential is due to my evaluation of what dollar value the log will ACTUALLY YIELD after processing.

It should be apparent by now that there is no answer to the question "What is a walnut tree worth?" The question is much like asking "What is a used car worth?" There are some exceptional used cars (Elvis Presley's gold plated cadillac) just as there are some exceptional walnut trees. One must recognize that no value for any commodity, walnut trees or used cars, can remotely be based on the extremely rare individual, but rather has to be based on the average of what really exists.

AREA OF ORIGIN

All timber buyers and/or walnut companies have a tremendous backlog of experience (successes and failures). As with most businesses, they use this experience as a basis for future investment. On the AVERAGE, trees from a given spot (area of origin) have a different value than trees from another spot. For ease of discussion I have separated area of origin into four classifications.

1) REGION--Is a very general classification. Different companies/buyers will use different boundaries. In the western part of the walnut range, northern and southern is often used and the boundary is approximately an east west line from St. Louis to Kansas City. Northern logs (on the average) are better than southern logs.

2) DISTRICT--Refers to a general area within a region. I think of a district as the approximate boundaries in which a buyer usually operates. In my case, this would be western Iowa and eastern Nebraska. There is a considerable difference between the average value of logs coming from different districts.

3) AREA--Refers to units within a District. Most buyers will consciously or unconsciously differentiate between areas. I have about ten different areas within my District. On the average, trees from different areas have a different value. I pay a different price for veneer logs (lumber logs remain constant) depending upon area. I do not have a good explanation for this difference, but assume it relates to some interaction of soil, moisture and/or other environmental or genetic factors which affect quality.

4) PAST HISTORY AND SETTING--Any abuse suffered in the past by the tree lowers its quality, Grazing (type of critter and intensidy), fire, herbicides, and any type of human or natural injury (equipment/storms) have a negative affect on the health/vigor and quality of the tree. The specific setting of the tree, eg. contigious timber stand, narrow bands of trees along field or streams, or trees in proximity to humans has an affect on tree quality. On the average, trees located within contigious stands are of better quality than those in narrow bands and both are better than those in rural or urban homesteads.

SIZE

Without exception, all other variables being equal, larger diameter logs are worth more per board foot than smaller diameter logs. One would think size is the one constant in determining value, but log rules and scaling methods differ.

The walnut industry uses the Doyle Log Rule and bases scale on:

1) Length to the nearest foot. Nine feet eight inches is nine feet. Lengths on veneer logs are extremely important. A log bucked at 8'1" has a drastically different value than the same log bucked at 8'6". Critical lengths relate to the requirements of the ultimate use of produced veneer. The same critical lengths apply to standing trees. Anyone who appraises or evaluates trees and guesses at the length of veneer logs does a disservice to all concerned.

2) Diameter inside the bark (DIB) at the smallest point in the log. Where DIB cannot be directly measured (standing tree, log cut at a limb swell, or log with crotch at small end), the DIB=circumference x 0.28. This formula takes into account bark thickness. It is not always exactly accurate, but is very close. For logs/trees over 100 inches in circumference (29 inches DIB and larger), the formula is circumference x 0.30=DIB.

I have on several occasions been told that log buyers are cheating people by using the Doyle Log Rule because it underestimates the actual board footage derived from small diameter logs.

One cannot cheat anyone based on the type of log scale used. You can only cheat someone if you pay less than a fair value for the tree. It really does not matter what log rule is used. The actual price paid for a given log is independent of the log rule used to estimate volume. . For example:

Log Rule	Lt.	Dia.	BF	$/BF	Total
Doyle	8	14	50	0.55	$27.50
International ¼"	8	14	65	0.42	27.30
Scribner Decimal C	8	14	60	0.46	27.60

DEFECTS

Bark characteristics, taper and width of sapwood are not actual defects, but are reliable indicators of wood quality. "Good or bad" bark characteristics are impossible to describe or demonstrate. They also vary from area to area. Most walnut buyers rely heavily on bark characteristics to determine value.

Taper is an indication of the first few years of height growth. Rapid initial height growth (less taper) normally indicates heavy competition when trees are young. With competition one would anticipate fewer low side limbs, early shedding of limbs, and fewer internal limb defects.

Sapwood width is also a reliable indication of log quality for essentially the same reasons as taper. Narrow sapwood indicates good log quality. The bark is a good external indicator of sapwood width. One should note that through bark, taper and width of sapwood the buyer tries to determine cleanness of log (lack of internal limb defects). Under proper plantation or native stand walnut management one will often have poor bark characteristics (to the buyer), average taper, and wide sapwood. As noted, these factors are not defects, but indicators of defects. Buyers/mills are interested in clean wood. My advice to owners is to properly prune trees to get clean wood and take periodic photographs to convince future walnut buyers of the quality of your product.

LIMB DEFECTS

There is a difference between limbs and limb defects. A limb is external to the bole of a tree. A limb defect is internal to the bole of a tree. A buyer only concerns himself with the internal defects. ANY indication of a limb defect is evaluated the same as an actual limb. I am often amused that many people believe pruning limbs off a tree immediately raises the value of the tree. In fact, larger limbs removed from larger trees often lowers value due to decay/discoloration/staining. The existence of a limb guarantees the presence of a limb defect, but the absence of limb does not preclude the existence of a limb defect.

HOLLOWS

I would hope that everyone recognizes a hollow tree greatly decreases in value. The hollow normally precludes any veneer and limits its value for lumber. The timber buyer is not often fooled (with experience some trees just lookhollow), but I do not know any buyer who does not occasionally get fooled. The real trick for a buyer is determining the size and extent of the hollow. Sometimes the hollow peaks out rapidly and sometimes it runs almost the length of the tree. You know you've got a problem when you stick a saw into a tree and mice come running out, but you're in real trouble when a skunk, opossum, or racoon scampers out. In all the trees we have cut, I have not seen anything that conflicts with the research of Dr. Alex Shigo's research concerning tree wounds and compartmentalization.

LIGHTNING

Lightning is one of the worst injuries a tree can sustain. It seldom kills the tree, but often opens the whole length of the bole to decay and discoloration. Even if decay has not severely progressed, it will almost always cause a ring shake. One should sell a lightning struck tree as soon as possible.

METAL

Timber buyers often feel paranoid about metal in trees. It seems people go to great lengths to nail fences, insulators, signs, deer stands and good-luck horse shoes to trees. Besides the obvious problems associated with damage to mill equipment, oron oxidizes and stains the wood a blue/black. Metal stain extends both above and below the metal site, which further deteriates the value.

BIRDPECK -- WORMS

Birdpeck and worms are hard to spot in a standing tree and are often difficult to see in a cut log. Both are severe defects, especially in veneer. One worm hole essentially lowers the veneer value the same as a limb defect. Birdpeck and worms are primarily a southern log problem but a small amount of peck and worms are found in northern logs.

COST SHARING INCENTIVES FOR BLACK WALNUT MANAGEMENT[1]

Robert W. Koenig[2]

Abstract.--Cost Sharing Incentives have been beneficial in encouraging black walnut management and where common sense is applied will yield reasonable returns on both the public and private investment. This paper presents a "Dirt Forester's" Common Sense approach on how cost sharing practices might best be applied. No attempt is made to give exact cost figures or scientifically prove what is eluded to. It is just 19 years of experience and observation speaking!

It is indeed a pleasure to return to my old Alma Mater and be able to impose a little practical, Dirt-Forestry philosophy on such a distinguished group of nut growing, nuts as you all are. The subject of cost-sharing incentives is one that has been near and dear to my heart for the past 19 years, since I have been associated with professional Forestry work in Indiana.

Let me say from the start that I am a "Die-Hard Conservative" that believes in as little Governmental intervention in private affairs as is absolutely necessary to insure the preservation of our free enterprise system of economics; but let me also make it crystal clear (that based on my experience) little or no forestry work would ever have been started in the private, non-industrial forests of Indiana without the ACP original cost- sharing program and the stepped-up application of forestry practices because of the addition of the FIP cost-sharing program in 1974. This is not to say there could not have been another way to stimulate these badly needed activities. But from recent studies conducted on the cost effectiveness of the first year of FIP practices (1974) throughout the United States[3], it certainly appears that most federal cost-sharing has been fairly cost effective with the practices involving black walnut leading the way. In fact black walnut tree planting practices showed an internal rate of return (IRR) of 14%, and black walnut timber stand improvement practices showed an IRR of 21.4%.

The first federal cost-sharing practices specifically taylored for black walnut in Indiana were initiated in the early 1960's as ACP practices A-7(B) for establishing a stand of black walnut trees and B-10(B) for improving a stand of black walnut trees. Although we have lived through REAP (Rural Environmental Assistance Program) in the early 1970's, and have graduated to FIP (Forestry Incentives Program), and have changed practices numbers several times, we still have the two basic practices: Tree Planting and Timber Stand Improvement with their several component parts.

Basically all cost-shared forestry practices whether for walnut or any species or species mix can be divided into one of two categories.

The first category includes those practices which insure the establishment of new black walnut stands such as: site prepareation, tree planting, firebreak and access road establishment and initial weed control.

The second category includes those practices which improve the quality and quantity of black walnut products grown such as: corrective pruning, side-limb pruning, pre-commercial thinning, crop tree release and maintenance of firebreak and access roads.

Undoubtedly, you have all been told that black walnut is very site specific in its requirements for surviving and maintaining reasonable growth rates. That has been proven unequivocably by the many plantation failures that have occurred over the past 25 years and before, because they were planted with no consideration for soil texture, soil depth, rooting limitations, available soil moisture, slope aspect, slope percent, accessibility for protection and cultural treatment, etc, etc. This same fact of "site specificity" affects the success of not only walnut planting but also all other cultural practices. For it does no reasonable good to try to release a walnut tree from undesirable competition such as weeds, shrubs, lower-valued trees or vines, if the walnut tree being released is growing on the wrong site! This would be a waste of both time and money for the growth response could never pay back the investment made.

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[1] Presented at the NNGA/Walnut Council Joint Meeting, Purdue University, West Lafayette, Indiana, on August 13, 1981.

[2] Assistant State Forester, Indiana Department of Natural Resources, Division of Forestry, Indianapolis, IN.

[3] "Timber Yield and Financial Return Performance of the 1974 Forestry Incentives Program", Mills, Thomas J. and Daria Cain, Research Paper Rm-204, Rocky Mountain Forest and Range Experiment Station, U.S.D.A.

Assuming that site is not a problem, then the proper sequence of component practices that go into establishing a stand of black walnut trees should be as follows:

1. Site preparation--this might be any one of the following treatments or a combination of treatments to get the land ready for the actual planting of trees. It is up to the responsible forester to determine the needs and make an estimate of cost per thousand trees to be planted using such treatment. Site preparation can run as low as just a few dollars per thousand trees planted to as high as several hundred dollars per thousand trees planted depending on the condition of the land and what needs to be remove to make it ready for planting.
   a. Plow and disc firm--good for level to gently rolling old fields--costs vary according to custom rates charged locally.
   b. Herbicide application in bands at least two weeks before planting--good for preparing old sod fields and weed invested areas where it is too steep to plow and no brush or trees are present to complete. Either Dowpon or Roundup has been used successfully. All label recommendation should be followed in handling and application rates.
   c. Bush hogging followed by herbicide application as above--use where small trees and shrubs are present and likely to be competive.
   d. Bulldozing and root raking--use only where larger trees (3" DBH and up) are the problem and only where site quality is excellent--this is too expensive to be economically justified on anything less than the best areas.
2. Tree planting-includes the cost of purchasing seedlings.
   a. Mechanical tree planting--best for larger plantings and areas that are level to gently rolling and easily accessible. Pre-emergence herbicide can normally be applied at the same time further reducing costs.
   b. Hand planting-small plantings, steep slopes or areas with poor access for motor vehicles.
3. Pre-emergence herbicide or initial weed control absolutely necessary if the plantation is to be successful. This must be applied during or immediately after planting and then at least once every spring for the first five years. Some of this may be eliminated by proper interplanting or preplanting of such species as Autumn Olive, European Black Alder, White Pine or Black Locust. Almost no corrective pruning is needed if interplanting is used.
4. Walnut as an interplanting, with pre-emergant herbicide spot sprayed around each interplanted walnut--good for rough sites, slightly doubtful landowners, etc.
   a. First plant white pine on 10'x10' spacing and let it capture the site (3 to 5 years).
   b. Then interplant walnut when the pine have their heads above the major weed competition.

Already, one can see that establishing black walnut is expensive and labor intensive and not for those who believe: "you just stick the damn things in the ground and let 'em grow!" That just won't get the job done. If you do not intend to take care of the planting, please, do not plant black walnut!

Assuming you are bound and determined to go on with it (planting and growing black walnut), then the rest of the steps fall under the category of Timber Stand Improvement and should take you up to the time when a commercial thinning is possible:

5. Fencing to keep livestock out of the plantation or out of a stand of native walnut trees is another prerequisite for growing walnut or any forest product in Indiana--this only includes interior fences and no cost sharing is allowed on boundary or road fences under either ACP or FIP.

6. Corrective Pruning - is only necessary when a tree fails to develop a straight, central stem and does not maintain a healthy, apically dominant terminal leader. Causes can be anyone of many, but usually one of these is most likely:

   a. Late frost kills terminal bud and lateral buds try to take over.

   b. Casebearer moth, shoot moth, or other insects which also kills the terminal bud.

   c. Mechanical damage such as ice, wind or birds breaking terminal leader.

   d. Genetically inferior stock--wants to be a bush rather than a tree. Usually corrective pruning won't work and the bad apple has to be removed.

7. Side Limb Pruning -- Can also be lessened by interplanting-must be done before diameter of pruned branches reach 2 inches and before bole (main stem of tree) reaches 10 inches in diameter at breast height (normally side limb pruning is done between 3 and 10 inches DBH).

8. Non-commercial thinning-means value of trees removed is less than the cost.

   a. For plantations follow the US Forest Service Guide "Quick Reference for Thinning Black Walnut" prepared by Burl Ashley of Northeastern Area State and Private Forestry, Morgantown, W.V. and Richard Schlesinger of North Central Forest Experiment Station, Carbondale, IL and published by the North Central Forest Experiment Station at St. Paul. This uses the Crown Competition Factor (CCF) to determine when to thin both for veneer-sawlog production and for nut-log production.

   b. For native or natural black walnut stands, stocking levels should be maintained 10 to 20% higher than suggested for plantation after the first pre-commercial thinning to avoid excessive epicormic sprouting and to guard against wind damage, sun scald, etc.

      By the time a second pre-commercial thinning is needed, stand density should be equal to the recommended stocking level for a plantation.

9. Maintenance of firebreaks and access roads--this usually pertains just to the practices needed to prevent erosion and sedimentation.

   a. Waterbars on steep slopes
   b. "Thankyou Mams" or drainage dips
   c. Box culverts
   d. Improved stream crossings
   e. Seeding, fertilizing, liming and mulching bare soil

So far, I have deliberately failed to mention cost-share rates and hold-down rates because in this discussion they are not important. What is important is that there is enough incentive to encourage people who have the good walnut growing sites and who have the determination to do what it takes to grow the walnut trees we need now and in the future.

U.S. Department of Agriculture, Forest Service.
Black walnut for the future. Gen. Tech. Rep. NC-74.
St. Paul, MN: U.S. Department of Agriculture,
Forest Service, North Central Forest Experiment
Station; 1982. 151 p.

Contains 33 papers presented at the third symposium on the culture of black walnut. Papers summarize the current information on walnut timber and nut production.

KEY WORDS: Insects, disease, silviculture, tree improvement, genetics

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Forest Service

North Central Forest Experiment Station

General Technical Report **NC-75**

Handbook for Predicting Slash Weight in the Northeast

Duane R. Freeman, Robert M. Loomis, and Peter J. Roussopoulos

GOVERNMENT PUBLICATIONS
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HANDBOOK FOR PREDICTING SLASH WEIGHT IN THE NORTHEAST

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Woody debris or "slash"—the foliage, branches, unmerchantable bole tips, and broken or defective boles of trees left on the ground after tree cutting fig. 1)—often poses a serious fire threat to forest resources. When weather conditions are conducive, fires encountering heavy accumulations of slash burn with high intensity, are generally difficult to control, and can quickly spread into surrounding stands of valuable timber. Where the risk of fire damage is high, management action to treat or remove slash accumulations is often desirable.

Whether slash treatment is necessary and which type of treatment is most effective in a particular situation are complex decisions involving a variety of factors. Among them are the amount of slash involved, land management objectives, resource values, land ownership and use patterns, topography, climate, vegetation types, fire frequency, fire effects, local fire suppression capability, slash disposal laws, and timber sale contract requirements.

This handbook focuses on the first of these factors, the amount of slash involved. While field inventory methods can be used to estimate slash weight (Roussopoulos and Johnson 1973), they are expensive and must be applied after cutting rather than before. The primary objective of this guide is to provide methods for predicting slash weight prior to cutting using common and easily obtainable tree measurements as independent variables (i.e., d.b.h. or, in some cases, d.b.h. with tree height). Tables are included that allow the user to estimate weights of crowns and unmerchantable bole tips, both on a "per tree" and a "per unit of tree basal area" basis for 10 coniferous species and 9 hardwood species (or species groups) common to forests of the North Central and Northeastern United States. Methods of estimating the weight of slash by standard fuel size classes are also included.

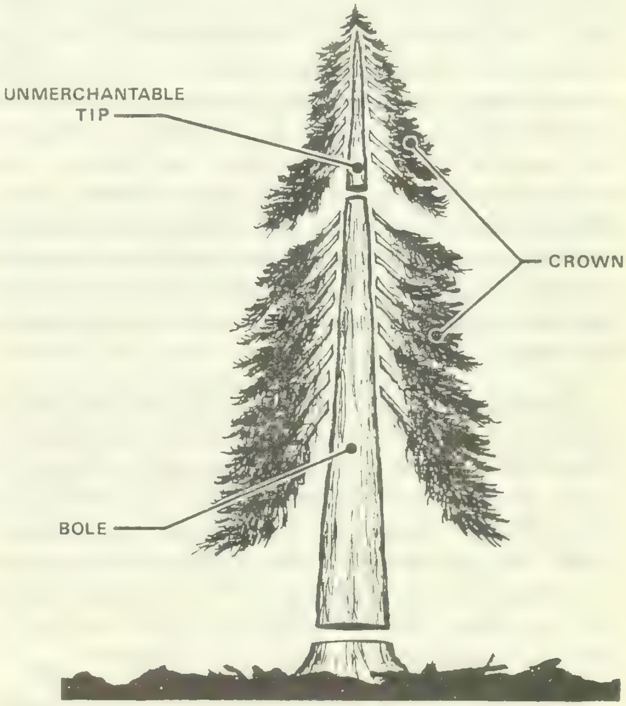

Figure 1.—*Slash is produced from three portions of the tree: (1) crown; (2) unmerchantable tip; and (3) defective or broken bole (adapted from Brown* et al. *1977).*

PREDICTING SLASH WEIGHT

In the slash weight prediction process, four sources of slash or debris are recognized: cutting, trampling, defect and breakage, and existing debris.

(a) Cutting debris consists of tree crowns and tops remaining on the site after cutting.
(b) Trampling debris is incidental material resulting from logging activities; it generally consists of small trees damaged during skidding or other logging operations.
(c) Breakage and defect is debris left on the site as cull material. The amount of debris can vary considerably by locality, site, age of the stand, timber sale operator, and timber sale requirements.
(d) Existing debris consists of material on the site prior to logging or precommercial thinning. A downed woody fuels inventory (Brown 1974) can be used to estimate the amount of existing debris.

Estimates of cutting and trampling debris can be made using the crown weight information presented in tables 1-7. These tables were generally patterned after those found in the *Handbook for Predicting Slash Weight of Western Conifers* (Brown *et al.* 1977) and in the *Handbook for Predicting Residue Weights of Pacific Northwest Conifers* (Snell and Brown 1980). In developing our tables we did not make allowances for differing stand conditions, although it is known, for example, that crown weight of red pine can vary with site quality and stand density (Brown 1963). The user should be aware that such differences exist, and that more precise slash weight estimates can be made by using additional variables such as site index and stand density (Brown 1965) or crown ratio (Loomis and Blank 1981).

The equations and sources of information used in constructing crown weight tables 1-7 are shown in Appendix I. Tables 1 and 2 list species requiring only d.b.h. as the independent variable for estimating crown weight. Tables 3-7 list species requiring both d.b.h. and tree height as the independent variables for estimating crown weight. If tree heights cannot be measured, estimated heights will suffice, although additional error may be introduced.

In tables 1-7, the "a" portions give weight per tree and the "b" portions give weight per square foot of basal area. Tables 2 and 7 list crown weights of hardwoods, but do not include foliage (fig. 2). Table 8 lists foliage weights of hardwoods, which can be added to the branchwood crown weights to predict total deb from summer harvest of hardwoods.

The equations and sources used in constructi table 8 are shown in Appendix II. Although the equ tions for hardwood crown weights and foliage weig were sometimes developed from different sourc the same species was used whenever possible. Wh this was not possible, species within the same gen were used.

The weights given in tables 1-8 include all cro branchwood, including the unmerchantable bole to a 4-inch top. Appendix III shows weight per tr and top diameter based on equations listed in A pendix I. Bole section weights as needed were add to weights shown in Appendix III to get the weigh listed in tables 1 and 2.

Wood densities needed for calculating sla resulting from defect and breakage, are given table 9.

The steps for using the tables to predict the weig of the various slash components are outlined bel

Step 1

Summarize tree harvest data by (a) number trees to be cut per acre by species and d.b.h. or basal area by species and d.b.h., whichever is m

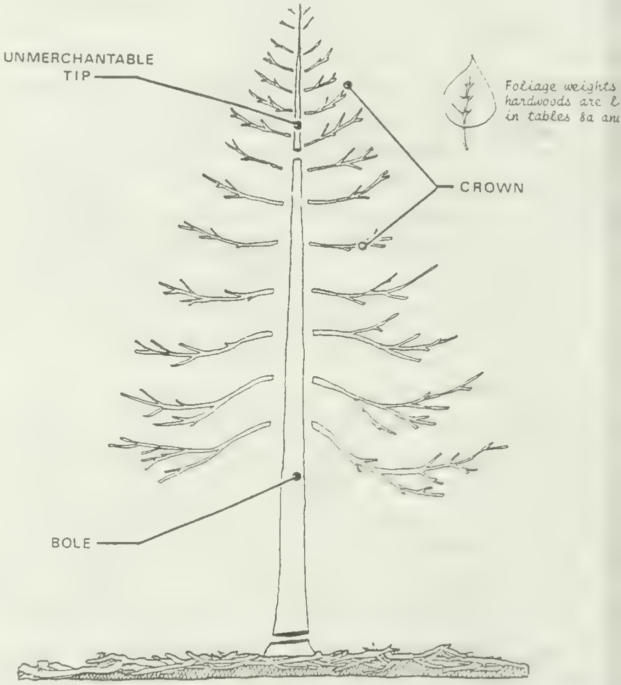

Figure 2.—*Crown weight tables for hardwoods not include foliage (adapted from Stanek and St 1978).*

convenient. Trees per acre can be converted to basal area per acre using table 10. Always use a d.b.h. distribution rather than an average stand diameter to avoid bias resulting from curvilinear weight relations.

Step 2

From the appropriate crown-weight table, multiply the number of trees times the weight for each d.b.h. and species category. Total the cutting debris for each species. Do the same with small-diameter trees that have been trampled during logging.

For stands of intolerant coniferous species with significant numbers of intermediate or suppressed crowns (fig. 3), crown weight should be adjusted by using the following equations (Brown *et al.* 1977):

D.b.h.	Equation
Less than 7.5 inches	$AW = W \times [1 - (0.5 \times f_I)]$
7.5 inches and greater	$AW = W \times [1 - (0.4 \times f_I)]$

where AW = adjusted weight per acre for intermediate crowns,
W = weight of crowns per acre calculated from the crown weight tables, and
f_I = the fraction of trees per acre having intermediate and suppressed crowns.

Step 3

Estimate slash weight in tons per acre for breakage and defect using the following equation:

$$W = \frac{(v) \times (f) \times (d),}{2{,}000}$$

where W = the weight of debris from defect and breakage in tons per acre,
v = merchantable volume to be cut in cubic feet per acre (note: 180 cu ft per MBF, 90 cu ft per cord),
f = fraction of merchantable volume expected to be left on the ground as defect and breakage, and
d = density of wood in pounds per cubic foot (from table 9).

Step 4

Summarize the total debris by adding:

(a) Weight of crowns or cutting debris.
(b) Weight of trampling debris.
(c) Weight of defect (cull) and breakage debris left in the woods.
(d) Weight of downed woody material or existing debris.

This will yield the total predicted weight of slash or debris remaining on the ground after cutting.

EXAMPLES OF SLASH PREDICTION

Example 1.—Commercial Thinning in a Red Pine Plantation

To determine the weight of cutting debris: assume 50 trees per acre are to be cut from each of three d.b.h. classes (5-, 6-, and 7-inch trees), with utilization to a 4-inch top diameter.

D.b.h. (in.)	Trees/acre	Lbs/tree (from table 1a)	Lbs/acre	Tons/acre
5	50	58	2,900	1.45
6	50	60	3,000	1.50
7	50	68	3,400	1.70
TOTAL			9,300	4.65

To determine the weight of trampling debris: assume that boles of trees damaged by trampling have been removed to a 4-inch top and only the slash from the crowns and unmerchantable tips remains on the site.

D.b.h. (in.)	Trees/acre	Lbs/tree (from table 1a)	Lbs/acre	Tons/acre
4	5	56	280	0.14

To determine the weight of defect and breakage debris: assume volume to be removed to be 670 cubic feet per acre; breakage of about 2 percent and defect left on the site of 3 percent (based on experience with similar red pine stands); and red pine density of 28.7 pounds per cubic foot (from table 9). Then, in the equation for determining weight (W), the volume (v) is 670, the fraction (f) of merchantable volume expected to be left on the site is 0.02 + 0.03 or 0.05, and the density (d) is 28.7, or

$$W = \frac{(v) \times (f) \times (d)}{2{,}000} = \frac{670 \times 0.05 \times 28.7}{2{,}000}$$
$$= 0.48 \text{ tons/acre.}$$

Thus, the total predicted slash from cutting = 4.65 + 0.14 + 0.48 = 5.27 tons per acre.

To determine the weight of downed woody material: assume the volume of existing downed debris to be 3 tons per acre.

Figure 3.—*The crown weights of intermediate and suppressed trees of shade-intolerant coniferous species are less than those of dominant or codominant trees, and adjustments in crown weights may be needed.*

The total predicted slash weight, therefore, becomes 8.27 tons per acre (5.27 + 3.0).

Example 2.—Clearcutting in an 80-year-old, Second-growth Northern Red Oak Stand

To determine the weight of cutting debris: assume harvest of 70 9-inch trees per acre, 100 10-inch trees per acre, and 50 11-inch trees per acre, with utilization to a 4-inch top diameter.

D.b.h. (in.)	Trees/acre	Lbs/tree (from table 2a)	Lbs/acre	Tons/acre
9	70	138	9,660	4.83
10	100	177	17,700	8.85
11	50	222	11,100	5.55
TOTAL			38,460	19.23

To determine the weight of trampling debris: assume all trees of merchantable size to be harvested with no damage from trampling.

To determine the weight of defect and breakage debris: assume a volume to be removed of 1,930 cubi feet per acre; breakage of 5 percent and defect lef on the site of 10 percent (based on experience wit similar northern red oak stands); and northern re oak density of 39.3 pounds per cubic foot (from tabl 9). Then, in the equation for determining weight (W) the volume (v) is 1,930, the fraction (f) of merchantable volume to be left on the site is 0.05 + 0.10 o 0.15, and the density (d) is 39.3, or

$$W = \frac{(v) \times (f) \times (d)}{2{,}000} = \frac{1{,}930 \times 0.15 \times 39.3}{2{,}000}$$

$$= 5.7 \text{ tons/acre.}$$

Thus, the total predicted slash from cutting = 19.23 + 0 + 5.7 = 24.93 tons per acre.

To determine the weight of downed woody mate rial: assume the volume of existing downed debri to be 5 tons per acre.

The total predicted slash weight, therefore, becomes 29.93 tons per acre (24.93 + 5.0).

Example 3.—Adjusting for Intolerant Coniferous Species

To determine the weight of cutting debris for stands of intolerant coniferous species with significant numbers of intermediate or suppressed crowns: assume the calculated crown weight for the stand to be 30,000 pounds per acre in trees 8 inches d.b.h. and greater, and the proportion of intermediate and suppressed crowns in the stand to be 25 percent.

Then, adjusted crown weight (AW) = W x [1−(0.4 x f_I)] = 30,000 x [1−(.4 x .25)] = 27,000 lbs/acre. Thus, the adjusted crown weight is about 14 tons per acre.

FUEL SIZE CLASSES

Fuel size class component fractions are given in tables 11 and 12. The weights of individual fuel size classes (foliage, branchwood 0 to 1/4-inch in diameter, 1/4 to 1 inch, 1 to 3 inches, and 3 inches and larger) (fig. 4) are needed if the fuel manager wishes to use debris prediction information to estimate fire behavior by computer (Radloff *et al.* 1982). These fuel size classes are used to predict fire behavior potential in the Rothermel (1972) fire behavior model. Also, the branchwood fuel size classes correspond to the 1-, 10-, 100-, 1,000-hour timelag fuels described in the National Fire Danger Rating System (Deeming *et al.* 1977). Some examples of predicting slash weights by fuel size classes are given below.

Example 1.—Conifers

The fuel loading in tons per acre for each size class is estimated using the crown component fractions from table 11 multiplied by the corresponding crown weight per acre for each species and d.b.h. class. In this example, we used the red pine stand described earlier. Since table 11 does not include component fractions for the 5- and 7-inch diameter classes, the fractions for the 6-inch category are used to represent the 5-, 6-, and 7-inch diameter classes. The total weight within each diameter class is multiplied by each crown component fraction to obtain weights within each fuel class size as shown below. For example, the 1.45 tons per acre in the 5-inch diameter class multiplied by the 0.28 fraction of foliage from table 11 equals 0.40 ton per acre of foliage.

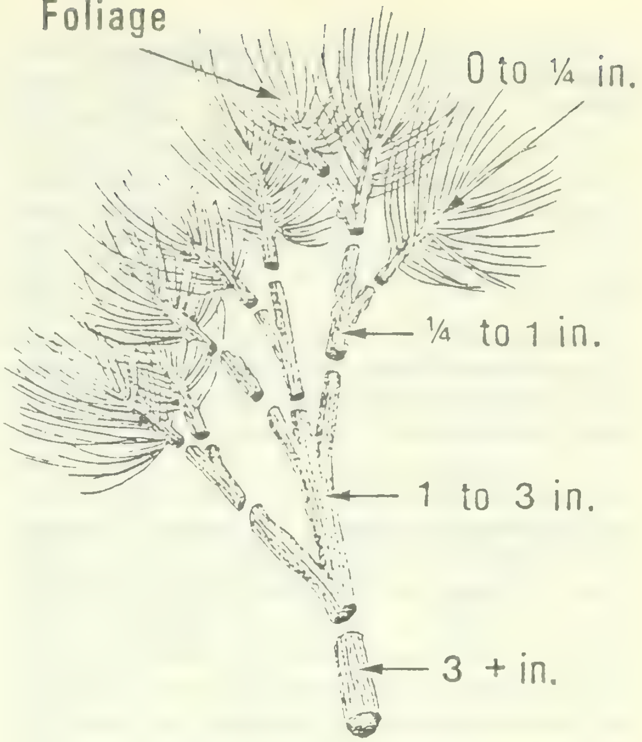
Foliage
0 to ¼ in.
¼ to 1 in.
1 to 3 in.
3 + in.

Figure 4.—*Component fractions of foliage and branchwood size classes are used for calculating tons per acre input for computer-based, fire-behavior predictions (adapted from Brown 1978).*

D.b.h. (Inches)	Total	Foliage	Fuel class size (inches)			
			0-¼	¼-1	1-3	3+
			Tons/acre			
4	0.14	0.03	0.01	0.02	0.02	0.06
5	1.45	.40	.06	.39	.34	.26
6	1.50	.42	.05	.40	.36	.27
7	1.70	.47	.07	.46	.40	.30
Total	4.79	1.32	.19	1.27	1.12	.89

Example 2.—Hardwoods

The fuel loadings for hardwood species are estimated using the crown component fractions from table 12 multiplied by the corresponding crown weight estimate for each d.b.h. class. In this example, we used the second-growth hardwood (northern red oak) stand described earlier. The total weight within each diameter class is multiplied by each crown component fraction to obtain weights within each fuel class size as shown below. For example, the 4.83 tons per acre of 9-inch slash multiplied by the 0.05 fraction of 0- to 1/4-inch material from table 12 equals 0.24 ton per acre of 0- to 1/4-inch material.

D.b.h. (inches)	Total	Fuel class size (inches)			
		0-¼	¼-1	1-3	3+
		Tons/acre			
9	4.83	0.24	1.06	2.80	0.73
10	8.85	.35	1.86	4.78	1.86
11	5.55	.22	1.11	2.72	1.50
Total	19.23	.81	4.03	10.30	4.09

For summer-cut trees, hardwood foliage estimates are calculated using weights from table 8a, multiplied by the number of harvested stems per acre.

D.b.h. (inches)	Trees/acre	Foliage	Foliage	Foliage
		Lbs/tree	*Lbs/acre*	*Tons/acre*
9	70	12	840	0.42
10	100	15	1,500	.75
11	50	17	850	.43
Total				1.60

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Table 1a.—*Crown weight (per tree), including unmerchantable tip to a 4-inch top, for selected coniferous species (weights above the dotted line are total tree weights including the tree bole; weights above the dashed lines are within the limits of sampled data)*

(In pounds per tree)

D.b.h. (inches)	Jack pine	Red pine	Pitch pine	Balsam fir	Black spruce	White spruce
1	2	2	2	1	1	1
2	10	10	10	7	8	8
3	28	26	26	20	22	22
4	54	56	60	56	55	56
5	66	58	64	67	63	69
6	80	60	71	81	74	85
7	100	68	85	99	89	104
8	123	79	104	121	106	127
9	150	95	127	146	125	152
10	182	115	156	173	145	180
11	218	142	187	203	168	210
12	257	177	223	236	192	243
13	299	222	266	271	218	277
14	345	281	313	308	245	314
15	395	356	365	348	274	352
16	448	454	421	390	305	393
17			484			437
18			551			482
19						528
20						577
21						628
22						681

Table 1b.—*Crown weight (per square foot of basa area), including unmerchantable tips to a 4-inc top, for selected coniferous species (weights abov the dotted line are total tree weights including th tree bole; weights above the dashed lines are withi the limits of sampled data)*

(In pounds per square foot)

D.b.h. (inches)	Jack pine	Red pine	Pitch pine	Balsam fir	Black spruce	White spruc
1	367	367	367	183	183	183
2	455	455	455	318	364	364
3	571	531	531	408	449	449
4	621	644	690	643	632	644
5	485	426	471	493	463	507
6	408	306	362	413	378	434
7	375	255	318	371	333	390
8	352	226	298	347	304	364
9	339	215	287	330	283	344
10	334	211	286	317	266	330
11	330	215	283	308	255	318
12	327	225	284	301	245	310
13	324	241	288	294	236	300
14	323	263	293	288	229	294
15	322	290	297	284	223	287
16	321	325	302	279	218	282
17			307			277
18			312			273
19						268
20						264
21						261
22						258

Table 2a.—*Crown weight*[1] *(per tree), including unmerchantable tip to a 4-inch top, for selected hardwoods (weights above the dotted lines are total tree weights including the tree bole; weights above the dashed lines are within the limits of sampled data)*

(In pounds per tree)

D.b.h. (inches)	Yellow-poplar	Red oaks	White oaks	Aspen	American beech	Red maple	Black cherry	Hickory
1	2	2	2	1	3	2	3	2
2	9	12	10	8	17	11	14	12
3	25	34	30	25	44	30	37	34
4	52	71	63	29	29	63	75	73
5	33	57	44	38	83	49	39	50
6	26	66	47	50	113	64	49	54
7	23	83	58	65	151	82	62	69
8	25	107	75	84	199	101	76	95
9	33	138	98	107	258	122	93	131
10	45	177	128	135	326	145	112	178
11	62	222	165	167	408	170	133	236
12	85	274	208	205	502	197	156	304
13	112	334	258	248	608	225	181	383
14	144	401	315	295	728	256	209	473
15	182	474	378	349	862	288	238	574
16	224	555	448	410	1,012	323	270	685
17	271	643	525	475	1,177			
18	323	738	608	546	1,356			
19	381	841	698	625				
20	443	950	794	711				
21	510	1,066	897					
22	582	1,190	1,007					
23		1,320	1,123					
24		1,458	1,246					
25		1,603	1,375					

[1] Foliage weight not included.

Table 2b.—*Crown weight*[1] *(per square foot of basal area), including unmerchantable tips to a 4-inch top, for selected hardwoods (weights above the dotted lines are total tree weights including the tree bole; weights above the dashed lines are within the limits of sampled data)*

D.b.h. (inches)	Yellow-poplar	Red oaks	White oaks	Aspen	American beech	Red maple	Black cherry	Hickory
1	367	367	367	183	550	367	550	367
2	409	545	455	363	773	500	636	545
3	510	694	612	510	898	612	755	693
4	598	816	724	333	333	724	862	839
5	243	419	324	279	610	360	287	368
6	133	337	240	255	577	327	250	276
7	86	311	217	243	566	307	232	258
8	72	307	215	241	570	289	218	272
9	75	312	222	242	584	276	210	296
10	83	325	235	248	598	266	206	327
11	94	336	250	253	618	258	201	358
12	108	349	265	261	639	251	199	387
13	121	362	280	269	659	244	196	415
14	135	375	295	276	681	239	196	442
15	148	386	308	284	702	235	194	468
16	160	398	321	294	725	231	193	491
17	172	408	333	301	747			
18	183	418	344	309	767			
19	193	427	354	317				
20	203	435	364	326				
21	212	443	373					
22	220	451	381					
23		458	389					
24		464	397					
25		470	403					

[1] Foliage weight not included.

Table 3a.—*Crown weight (per tree), including unmerchantable tip to a 4-inch top, for* **eastern hemlock** *(weights above the dotted line are total tree weights)*

(In pounds per tree)

D.b.h. (inches)	Total height (feet)						
	5	10	20	30	40	50	60
<6	1	3	23	72			
6					22	15	
7					33	23	
8					46	33	
9					62	47	
10						63	43
11						81	56
12						102	73
13						126	93
14						153	115
15						183	140

Table 3b.—*Crown weight (per square foot of basal area), including unmerchantable tips to a 4-inch top, for* **eastern hemlock** *(weights above the dotted line are total tree weights)*

(In pounds per square foot)

D.b.h. (inches)	Total height (feet)						
	5	10	20	30	40	50	60
<6	183	136	469	529			
6					112	77	
7					124	86	
8					132	95	
9					140	106	
10						116	79
11						123	85
12						130	93
13						137	101
14						143	108
15						149	114

Table 4a.—*Crown weight (per tree), including unmerchantable tip to a 4-inch top, for* **red spruce** *(weights above the dotted line are total tree weights)*

(In pounds per tree)

D.b.h. (inches)	Total height (feet)							
	5	10	20	30	40	50	60	70
<6	1	5	21	54				
6					28	18		
7					41	29	15	
8					58	42	24	
9						58	36	
10						78	51	21
11						101	69	32
12						128	89	47
13							114	64
14							142	85
15							172	108

Table 4b.—*Crown weight (per square foot of basal area), including unmerchantable tips to a 4-inch top, for* **red spruce** *(weights above the dotted line are total tree weights)*

(In pounds per square foot)

D.b.h. (inches)	(In pounds per square foot)							
	5	10	20	30	40	50	60	70
<6	183	227	429	621				
6					142	92		
7					153	109	56	
8					166	120	69	
9						131	81	
10						143	94	39
11						153	104	48
12						163	113	60
13							124	69
14							133	80
15							140	88

Table 5a.—*Crown weight (per tree), including unmerchantable tip to a 4-inch top for* ***eastern white pine*** *(weights above the dotted line are total tree weights)*

(In pounds per tree)

D.b.h. (inches)	Total height (feet)								
	5	10	20	30	40	50	60	70	80
<6	1	2	11	32					
6					29	20			
7					42	32	19		
8						45	30		
9						62	43	22	
10						82	59	33	
11							78	47	14
12							100	64	25
13								84	38
14								106	54
15								132	73

Table 5b.—*Crown weight (per square foot of basal area), including unmerchantable tips to a 4-inch top for* ***eastern white pine*** *(weights above the dotted lines are total tree weights)*

(In pounds per square foot)

D.b.h. (inches)	Total height (feet)								
	5	10	20	30	40	50	60	70	80
<6	183	367	500	653					
6					148	102			
7					157	120	71		
8						129	86		
9						140	97	50	
10						150	108	61	
11							118	71	21
12							127	82	32
13								91	41
14								99	51
15								108	59

Table 6a.—*Crown weight (per tree), including unmerchantable tip to a 4-inch top for* ***northern white-cedar*** *(weights above the dotted line are total tree weights)*

(In pounds per tree)

D.b.h. (inches)	Total height (feet)					
	5	10	20	30	40	50
<6	1	4	26			
6				21	25	
7				16	31	
8					38	
9					45	
10					52	55
11					60	64
12					68	73

Table 6b.—*Crown weight (per square foot of basal area), including unmerchantable tips to a 4-inch top for* ***northern white-cedar*** *(weights above the dotted line are total tree weights)*

(In pounds per square foot)

D.b.h. (inches)	Total height (feet)					
	5	10	20	30	40	50
<6	183	182	299			
6				107	127	
7				60	116	
8					109	
9					102	
10					95	101
11					91	97
12					87	93

Table 7a.—*Crown weight*[1] *(per tree), including unmerchantable tip for* ***paper birch*** *(weights above the dotted line are total tree weights)*

(In pounds per tree)

D.b.h. (inches)	Total height (feet)							
	5	10	20	30	40	50	60	70
<6	0.5	1	5	22				
6					31	22		
7					49	36		
8					68	55	34	
9					91	72	49	25
10							69	38
11							92	55
12							120	77

[1] Foliage weight not included. Crown weights from the original sources (Young *et al.* 1964, Young and Carpenter 1967) included foliage. To estimate weights listed here, foliage weights (Storey and Pong 1957) from Table 8a were subtracted from the original crown weights.

Table 7b.—*Crown weight*[1] *(per square foot of basal area), including unmerchantable tips to a 4-inch top for* ***paper birch*** *(weights above the dotted line are total tree weights)*

(In pounds per square foot)

D.b.h. (inches)	Total height (feet)							
	5	10	20	30	40	50	60	70
<6	92	183	227	253				
6					158	112		
7					184	135		
8					195	158	97	
9					206	163	111	57
10							127	70
11							139	83
12							152	98

[1] Foliage weight not included.

Table 8a.—*Foliage weight (per tree) for selected hardwoods (weights above the dashed lines are within the limits of sampled data)*
(In pounds per tree)

D.b.h. (inches)	Yellow-poplar	Red oak	White oak	Aspen	American beech	Maple	Cherry	Hickory	Birch
1	0.2	0.5	0.4	0.1	0.3	0.1	0.3	0.1	0.2
2	.6	1	1	.5	1	.5	1	.5	1
3	1	2	3	1	3	1	2	1	2
4	2	4	4	2	5	2	4	3	4
5	3	5	7	4	8	4	7	5	5
6	5	7	9	5	12	6	10	7	8
7	6	9	12	7	17	9	13	10	10
8	8	10	15	10	22	13	17	14	13
9	9	12	19	12	28	18	21	19	17
10	11	15	22	16	35	23	26	24	21
11	13	17	27	19	42	29	32	30	25
12	15	19	31	23	50	37	38	37	29
13	18	22	36	27	59	45	44	44	34
14	20	24	41	32	69	54	51	53	39
15	23	27	46	37	80	65	59	62	45
16	26	30	51	42	91	76	66	73	
17	29	32	57	48	103			84	
18	32	35	63	54	116			96	
19	35	38	70	60				109	
20	38	41	76	67				123	
21	42	44						138	
22	45	48						154	
23	49	51						171	
24	53	54							
25	57	58							

Table 8b.—*Foliage weight (per square foot of basal area) for selected hardwoods (weights above the dashed lines are within the limits of sampled data)*
(In pounds per square foot of basal area)

D.b.h. (inches)	Yellow-poplar	Red oak	White oak	Aspen	American beech	Maple	Cherry	Hickory	Birch
1	37	91	73	18	55	18	55	18	37
2	27	45	45	23	45	23	45	23	45
3	20	41	61	20	61	20	41	20	41
4	23	46	46	23	57	23	46	34	46
5	22	37	51	29	59	29	51	37	37
6	26	36	46	26	61	31	51	36	41
7	22	34	45	26	64	34	49	37	37
8	23	29	43	29	63	37	49	40	37
9	20	27	43	27	63	41	48	43	38
10	20	28	40	29	64	42	48	44	39
11	20	26	41	29	64	44	48	45	38
12	19	24	39	29	64	47	48	47	37
13	20	24	39	29	64	49	48	48	37
14	19	22	38	30	65	51	48	50	37
15	19	22	37	30	65	53	48	51	37
16	19	21	37	30	65	54	47	52	
17	18	20	36	30	65			53	
18	18	20	36	31	66			54	
19	18	19	36	31				55	
20	17	19	35	31				56	
21	17	18						57	
22	17	18						58	
23	17	18						59	
24	17	17							
25	17	17							

Table 9.—*Specific gravities and densities of selected North Central and Northeastern tree species*

Species	Scientific name	Specific gravity[1]	Density
CONIFERS			[2]*Lbs/ft*^{3}
Northern white-cedar	*Thuja occidentalis* L.	0.31	19.3
Balsam fir	*Abies balsamea* (L.) Mill.	.36	22.5
Eastern hemlock	*Tsuga canadensis* (L.) Carr.	.40	25.0
Jack pine	*Pinus banksiana* Lamb.	.43	26.8
Pitch pine	*Pinus rigida* Mill.	.52	32.6
Red pine	*Pinus resinosa* Ait.	.46	28.7
Virginia pine	*Pinus virginiana* Mill.	.48	30.0
Eastern white pine	*Pinus strobus* L.	.35	21.8
Black spruce	*Picea mariana* (Mill.) B.S.P.	.40	25.0
Red spruce	*Picea rubens* Sarg.	.41	25.6
White spruce	*Picea glauca* (Moench) Voss	.40	25.0
Tamarack	*Larix laricina* (Du Roi) K. Koch	.53	33.1
HARDWOODS			
Quaking aspen	*Populus tremuloides* Michx.	.38	23.7
American beech	*Fagus grandifolia* Ehrh.	.64	39.9
Paper birch	*Betula papyrifera* Marsh.	.55	34.3
Yellow birch	*Betula alleghaniensis* Britton	.62	38.7
Black cherry	*Prunus serotina* Ehrh.	.50	31.2
Hickory	*Carya* spp. Nutt.	.72	44.9
Red maple	*Acer rubrum* L.	.54	33.7
Sugar maple	*Acer saccharum* Marsh.	.63	39.3
Northern red oak	*Quercus rubra* L.	.63	39.3
White oak	*Quercus alba* L.	.68	42.4
Yellow-poplar	*Liriodendron tulipifera* L.	.42	26.2

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[1] Weight when ovendry and volume at 12 percent moisture content. Table A-4-2, U.S. Forest Products Laboratory, Wood Handbook, USDA Handbook 72 (Rev. 1974), p. 4-41 to 4-55. U.S. Government Printing Office, Washington, D.C.

[2] The average density for coniferous forest types in the Northeast is 26.2 pounds cubic foot and 38.1 pounds cubic foot for hardwood types. To obtain wood densities in pounds per cubic foot, multiply the specific gravity by 62.4.

Table 10.—*Basal area*[1] *table*[2]

(In square feet)

Diameter (inches)	Trees (number)									
	1	2	3	4	5	6	7	8	9	10
2	0.02	0.04	0.07	0.09	0.11	0.13	0.15	0.17	0.20	0.22
3	.05	.10	.15	.20	.25	.29	.34	.39	.44	.49
4	.09	.17	.26	.35	.44	.52	.61	.70	.79	.87
5	.14	.27	.41	.55	.68	.82	.95	1.09	1.23	1.36
6	.20	.39	.59	.79	.98	1.18	1.37	1.57	1.77	1.96
7	.27	.53	.80	1.07	1.34	1.60	1.87	2.14	2.41	2.67
8	.35	.70	1.05	1.40	1.75	2.09	2.44	2.79	3.14	3.49
9	.44	.88	1.33	1.77	2.21	2.65	3.09	3.53	3.98	4.42
10	.55	1.09	1.64	2.18	2.73	3.27	3.82	4.36	4.91	5.45
11	.67	1.32	1.98	2.64	3.30	3.96	4.62	5.28	5.94	6.60
12	.79	1.57	2.36	3.14	3.93	4.71	5.50	6.28	7.07	7.85
13	.92	1.84	2.77	3.69	4.61	5.53	6.45	7.37	8.30	9.22
14	1.07	2.14	3.21	4.28	5.35	6.41	7.48	8.55	9.62	10.69
15	1.23	2.45	3.68	4.91	6.14	7.36	8.59	9.82	11.04	12.27
16	1.40	2.79	4.19	5.59	6.98	8.38	9.77	11.17	12.57	13.96
17	1.58	3.15	4.73	6.31	7.88	9.46	11.03	12.61	14.19	15.76
18	1.77	3.53	5.30	7.07	8.84	10.60	12.37	14.14	15.90	17.67
19	1.97	3.94	5.91	7.88	9.84	11.81	13.78	15.75	17.72	19.69
20	2.18	4.36	6.54	8.73	10.91	13.09	15.37	17.45	19.63	21.82
21	2.41	4.81	7.22	9.62	12.03	14.43	16.84	19.24	21.65	24.05
22	2.64	5.28	7.92	10.56	13.20	15.84	18.48	21.12	23.76	26.40
23	2.89	5.77	8.66	11.54	14.43	17.31	20.20	23.08	25.97	28.85
24	3.14	6.28	9.42	12.57	15.71	18.85	21.99	25.13	28.27	31.42
25	3.41	6.82	10.23	13.65	17.04	20.45	23.86	27.27	30.68	34.09
26	3.69	7.37	11.06	14.75	18.44	22.12	25.81	29.50	33.18	36.87
27	3.98	7.95	11.93	15.90	19.88	23.86	27.83	31.81	35.78	39.76
28	4.28	8.55	12.83	17.10	21.38	25.66	29.93	34.21	38.48	42.76
29	4.59	9.17	13.76	18.35	22.93	27.52	32.11	36.70	41.28	45.87
30	4.91	9.82	14.73	19.63	24.54	29.45	34.36	29.27	44.18	49.09

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[1] To find the basal area (B.A.) in square feet from a diameter (D) measurement in inches, use the equation:

$$B.A. = \frac{\pi D^2}{4 \times 144} = 0.00545415D^2.$$

[2] Forbes, R. D. 1961. Forestry handbook. Society of American Foresters, 1955. The Ronald Press, New York. Adapted by E. T. Hawes, U.S. Forest Service, from H. H. Chapman and D. B. Demeritt. Elements of forest mensuration. J. B. Lyon Co., 1936.

Table 11.—*Fraction of crown component weight*[1] *(per tree), including unmerchantable tip to a 4-inch top, for selected coniferous species by fuel size classes*

D.b.h. (inches)	Jack pine	Red pine Pitch pine	Balsam fir	Spruce	Hemlock	White pine	White cedar
			FOLIAGE				
2	0.19	0.26	0.41	0.33	0.26	0.27	0.32
4	.13	.18	.28	.26	.18	.16	.27
6	.22	.28	.37	.35	.27	.25	.37
8	.25	.28	.37	.36	.29	.27	.39
10	.27	.30	.40	.38	.32	.31	.41
12	.26	.26	.35	.34	.30	.27	.37
14	.26	.26	.35	.34	.31	.29	.38
16	.23	.20	.29	.30	.26	.25	.34
18		.21	.29	.30		.25	.34
20				.24		.22	
			BRANCHWOOD 0 to 1/4 inch				
2	0.12	0.04	0.16	0.16	0.13	0.14	0.08
4	.09	.02	.11	.13	.10	.09	.06
6	.17	.03	.15	.19	.15	.14	.09
8	.20	.03	.15	.20	.16	.17	.09
10	.22	.04	.16	.21	.17	.18	.10
12	.21	.03	.14	.21	.15	.19	.09
14	.22	.03	.14	.21	.16	.20	.09
16	.21	.02	.12	.19	.13	.19	.08
18		.02	.12	.19		.20	.08
20				.18		.20	
			BRANCHWOOD 1/4 to 1 inch				
2	0.12	0.21	0.14	0.13	0.13	0.13	0.17
4	.10	.17	.11	.12	.10	.10	.15
6	.20	.27	.17	.17	.16	.16	.22
8	.26	.32	.23	.21	.20	.21	.26
10	.29	.35	.24	.23	.22	.23	.27
12	.30	.34	.29	.25	.24	.26	.27
14	.27	.35	.30	.26	.25	.27	.28
16	.25	.33	.32	.27	.26	.28	.26
18		.33	.33	.27		.29	.26
20				.28		.29	
			BRANCHWOOD 1 to 3 inches				
2	0.48	0.43	0.25	0.33	0.41	0.40	0.37
4	.13	.17	.11	.10	.13	.13	.11
6	.17	.24	.15	.14	.20	.19	.16
8	.15	.25	.15	.14	.21	.18	.17
10	.13	.23	.14	.13	.19	.16	.16
12	.18	.28	.18	.16	.25	.19	.22
14	.21	.27	.18	.16	.24	.18	.22
16	.28	.31	.25	.22	.31	.23	.30
18		.31	.24	.21		.22	.30
20				.29		.26	
			BRANCHWOOD 3 + inches				
2	0.08	0.06	0.04	0.05	0.07	0.06	0.06
4	.54	.46	.39	.39	.48	.52	.41
6	.24	.18	.16	.15	.22	.26	.16
8	.13	.12	.09	.09	.14	.17	.09
10	.09	.08	.06	.05	.09	.12	.06
12	.05	.09	.04	.04	.06	.09	.04
14	.04	.09	.03	.03	.04	.06	.03
16	.03	.13	.02	.02	.03	.05	.02
18		.13	.02	.02		.04	.02
20				.01		.03	

[1] Fractions were developed from tables and equations for similar western species using information from Brown *et al.* (1977) and Brown (1978).

Table 12.—*Fraction of crown branchwood*[1] *(per tree), including unmerchantable tip to a 4-inch top, by fuel size classes*
(In inches)

D.b.h. (inches)	Aspen				Oak and other hardwoods			
	0-¼	¼-1	1-3	3+	0-¼	¼-1	1-3	3+
1	0.14	0.31	0.55	0.00	0.09	0.05	0.86	0.00
2	.16	.24	.60	.00	.05	.11	.84	.00
3	.16	.31	.53	.00	.03	.13	.32	.52
4	.12	.28	.22	.38	.04	.18	.36	.42
5	.14	.33	.24	.29	.05	.21	.40	.34
6	.14	.35	.29	.22	.05	.23	.46	.26
7	.15	.36	.34	.15	.05	.23	.52	.20
8	.14	.35	.39	.12	.05	.23	.57	.15
9	.14	.34	.43	.08	.05	.22	.58	.15
10	.13	.33	.46	.08	.04	.21	.54	.21
11	.13	.32	.47	.08	.04	.20	.49	.27
12	.12	.30	.50	.08	.04	.19	.46	.31
13	.12	.29	.50	.09	.04	.18	.42	.36
14	.11	.28	.52	.09	.03	.17	.40	.40
15	.11	.27	.52	.10	.03	.16	.37	.44
16	.10	.26	.53	.11	.03	.15	.35	.47
17	.10	.25	.53	.12	.03	.14	.33	.50
18	.09	.24	.54	.13	.03	.14	.30	.53
19	.09	.23	.55	.13	.03	.13	.29	.55
20	.09	.22	.55	.14	.02	.12	.28	.58
21					.02	.12	.26	.60
22					.02	.11	.25	.62
23					.02	.11	.24	.63
24					.02	.10	.23	.65
25					.02	.10	.22	.66

[1] Fractions for aspen are from Loomis and Roussopoulos (1978), while those for oak and other hardwoods are from Loomis and Blank (1981).

APPENDIX I.

Equations and sources for crown weight prediction tables.

Species	D.b.h.	Equation[1]	[2] r^2	Source	Location	Top diameter
	Inches					Inches
CONIFERS						
Northern white-cedar	<6	$W = 0.0108H^{2.07}+0.0040H^{2.37}+0.0016H^{3.07}$	0.89	Dyer 1967	Maine	tree
	≥6	$W = 0.01887D^{1.41}H^{1.59}-0.00243D^{1.39}H^{2.06}$	.91	Dyer 1967	Maine	4.0
Balsam fir	<4	$W = 1.2189D^{2.53}$	.96	Baskerville 1965	Eastern Canada	tree
	≥4	$W = 2.2728D^{1.845}$	.96	Roussopoulos[3] 1978	Minnesota	2.5
Eastern hemlock	<6	$W = 0.0078H^{2.192}+0.0048H^{2.320}+0.00536H^{3.343}$	.94	Young and Carpenter 1967	Maine	0.0
	≥6	$W = 0.03711D^{2.1679}H^{0.4292}-0.0498D^{2.0215}H^{0.9670}$	.98	Young *et al.* 1964	Maine	4.0
Jack pine	<4	$W = 1.2189D^{2.53}$	.99	Hegyi 1972	Eastern Canada	tree
	≥4	$W = 1.5914D^{2.0270}$	.91	Sando and Wick 1972	Great Lakes Region	2.5
Pitch pine	<4	$W = 2.0243D^{2.3373}$	.99	Whittaker and Woodwell 1968	New York	tree
	≥4	$W = 2.0243D^{2.3373}-1.4469D^{2.3261}$	.99	Whittaker and Woodwell 1968	New York	0.0
Red pine	<4	$W = 2.0243D^{2.3373}$ (pitch pine used)	--	---	---	---
	≥4	$W = 8.076(1.284)^D$	.91	Brown 1963	Michigan	1.5
White pine	<6	$W = 0.00495H^{1.750}+0.00333H^{2.064}+.00185H^{2.814}$	.89	Young and Carpenter 1967	Maine	tree
	≥6	$W = 0.4464D^{2.1679}H^{0.4292}0.0585D^{2.0215}H^{0.9670}$	.98	Young *et al.* 1964	Maine	4.0
Black spruce	<4	$W = 1.413D^{2.48}$ (white spruce used)	--	---	---	---
	≥4	$W = 2.5986D^{1.7052}$	.90	Roussopoulos[3] 1978	Minnesota	2.5
Red spruce	<6	$W = 0.0397H^{1.626}+0.01378H^{1.847}+0.00999H^{2.705}$	.94	Young and Carpenter 1967	Maine	tree
	≥6	$W = 0.4848D^{2.1679}H^{0.4292}-0.0659D^{2.0215}H^{0.9670}$	.98	Young *et al.* 1964	Maine	4.0
White spruce	<4	$W = 1.413D^{2.48}$	.98	Baskerville 1965	Eastern Canada	tree
	≥4	$W = 5.5208 x Cf$[4]$ x D^{1.753}$	.82	Keen 1963	Eastern Canada	3.0
HARDWOODS						
Aspen	<4	$W = 0.3640D^{1.8545}+1.0246D^{2.7859}$	.85	Ribe 1973	Maine	tree
	≥4	$W = 7.0+0.4162D^{2.5094}-0.1235D^{2.1012}$	.97	Loomis and Roussopoulos 1978	Minnesota	3.0

(Appendix I. continued on next page)

(Appendix I. continued)

Species	D.b.h.	Equation[1]	[2]r^2	Source	Location	Top diam
	Inches					Inches
American beech	<4	$W = 0.8743D^{1.5402}+2.5854D^{2.4868}$	0.79	Ribe 1973	Maine	tree
	≥ 4	$W = 0.837D^{2.552}$	.987	Storey and Pong 1957	North Carolina	0.0
Paper birch	<6	$W = 0.00219H^{2.116}+0.00188H^{2.276}+0.00178H^{2.739}$	.97	Young and Carpenter 1967	Maine	tree
	≥ 6	$W = 0.5705D^{2.1679}H^{0.4292}-0.0721D^{2.0215}H^{0.9670}$	.97	Young *et al.* 1964	Maine	4.0
Black cherry	<5	$W = 2.5881D^{2.42530}$	.994	Wiant *et al.* 1977	West Virginia	tree
	≥ 5	$W = 20.48931+1.07958D^2-1.67602D$	.811	Wiant *et al.* 1977	West Virginia	4.0
Hickory	<5	$W = 1.93378D^{2.62090}$	.987	Wiant *et al.* 1977	West Virginia	tree
	≥ 5	$W = 191.16897+5.36555D^2-54.98699D$	.842	Wiant *et al.* 1977	West Virginia	[illegible]
Red maple	<5	$W = 1.81301D^{2.56226}$	.981	Wiant *et al.* 1977	West Virginia	tree
	≥ 5	$W = 0.93846D^2+5.18726D-0.55683$	.793	Wiant *et al.* 1977	West Virginia	4.0
Red oaks	<5	$W = 2.09014D^{2.54052}$	.989	Wiant *et al.* 1977	West Virginia	tree
	≥ 5	$W = 114.40758+3.55460D^2-29.31907D$	.891	Wiant *et al.* 1977	West Virginia	4.0
White oaks	<5	$W = 1.68565D^{2.60982}$	.985	Wiant *et al.* 1977	West Virginia	tree
	≥ 5	$W = 124.89440+3.31160D^2-32.77917D$	.910	Wiant *et al.* 1977	West Virginia	4.0
Yellow-poplar	<5	$W = 1.57792D^{2.51532}$	.995	Wiant *et al.* 1977	West Virigina	tree
	≥ 5	$W = 146.29742+2.49589D^2-35.08911D$	.732	Wiant *et al.* 1977	West Virginia	4.0

---

[1] W = weight in lbs/tree; D = d.b.h. in inches; H = tree height in feet.

[2] r^2 = coefficient of determination.

[3] Unpublished secondary analysis of data from Sando and Wick (1972).

[4] Assume fresh debris (including foliage, wood, and bark) had a moisture content of 85 percent. Original data were reported as fresh weights. Dry weight was computed using $Cf = \frac{1}{1+\frac{85}{100}} = 0.541$.

APPENDIX II.

Equations and sources for hardwood foliage weight tables.

Species and equation[1]	[2] r^2	Source
Aspen		
$W = 0.1235D^{2.1012}$	0.98	Loomis and Roussopoulos 1978
American beech		
$W = 0.311D^{2.048}$	.96	Storey and Pong 1957
Birch		
$W = 0.243D^{1.928}$	.93	Storey and Pong 1957
Cherry (Prunus pensylvanica)		
$W = 0.2759D^{1.9784}$	.87	Ribe 1973
Hickory		
$W = 0.101D^{2.372}$	.97	Storey and Pong 1957
Maple		
$W = 0.066D^{2.544}$	.87	Storey and Pong 1957
Red oak (Quercus rubra)		
$W = 0.4590D^{1.5018}$	.96	Loomis and Blank 1981
White oak (Quercus alba)		
$W = 0.3802D^{1.77}$	[3]	Ralston and Prince 1965
Yellow-poplar		
$W = 0.188D^{1.775}$	.92	Storey and Pong 1957

[1] W = weight in pounds; D = d.b.h. in inches.

[2] r^2 = coefficient of determination.

[3] Information not available.

APPENDIX III.

Crown weight[1] based on equations listed in Appendix I and used to construct tables to include unmerchantable bole tips to a 4-inch top (weights above the dashed lines are within the limits of sampled data)

(In pounds per tree)

	Species and unmerchantable tip diameter (in inches)							
D.b.h.	Jack pine[2]	Red pine[3]	Pitch pine[4]	Balsam fir[2]	Black spruce[2]	White spruce[5]	Aspen[6]	American beech[6]
(inches)	2½	1½	0	2½	2½	3	3	0
4	26	22	15	29	28	34	18	29
5	42	28	26	44	40	50	27	51
6	60	36	40	62	55	69	39	81
7	82	46	57	82	72	90	55	120
8	108	60	79	105	90	114	74	169
9	136	77	104	131	110	141	98	228
10	169	98	134	159	132	169	126	298
11	205	126	167	190	155	200	159	381
12	245	162	205	223	180	233	197	475
13	288	208	248	258	206	268	240	583
14	335	267	296	296	234	305	288	704
15	385	343	348	336	263	344	342	840
16	439	441	405	379	294	385	403	990
17			468			429	469	1,156
18			536			474	541	1,337
19						521	620	
20						570	706	
21						621		
22						674		

---

[1] Crown weight for conifers includes foliage; crown weight for hardwoods does not include foliage.

[2] For jack pine balsam fir, and black spruce, Lagrange interpolation equations and weights of 3-, 4-, and 6-inch tips for lodgepole pine, grand fir, and Englemann spruce (Brown *et al.* 1977) were used to calculate the weight of a 2-inch tip for each d.b.h. class. The weights of tips were subtracted from the 4-inch tips to get weights of the 2-inch to 4-inch tips. Then, weights of the 2- to 4-inch bole sections were converted to volumes by dividing by the densities of lodgepole pine, grand fir, and Engleman spruce respectively; then the volumes were converted back to weights of jack pine, balsam fir, and black spruce by multiplying these volumes by densities of jack pine, balsam fir, and black spruce respectively.

[3] For red pine, calculations were made similar to the above, using ponderosa pine information and a Lagrange interpolation equation for a 1-inch top.

[4] Equation for branches only and does not include the tree bole. Weights by d.b.h. of unmerchantable bole tips to a 4-inch top for ponderosa pine (Brown *et al.* 1977) were used, then converted to volumes by dividing by the density of ponderosa pine; then the volumes were converted back to weights of pitch pine by multiplying by the density of pitch pine.

[5] Equation based on a 3-inch top. The difference between a 3-inch top and a 4-inch top of Englemann spruce (Brown *et al.* 1977) was used to get the weight of the 3- to 4-inch bole section. Then, using the method described above for pitch pine, weights of the 3- to 4-inch bole sections were converted to volumes and back to weights.

[6] For aspen and American beech, information on tip weights of northern red oak was used to calculate weights of tips for each d.b.h. class.

APPENDIX IV.
Conversion Factors

All units are presented in U.S. standard measurements regardless of the units given in the source reference. The units can be converted to metric (SI) measurements using the following conversion factors:

To convert:	to:	Multiply by:
inches	centimeters	2.540
feet	meters	0.3048
chains	meters	20.12
acres	hectares	0.4047
cubic feet	cubic meters	0.02832
pounds	grams	453.59
pounds	kilograms	0.45359
tons per acre	kilograms per square meter	0.2243

U.S. Standard Measurement Conversions:

To convert tons per acre to cords or cunits per acre, take the pounds per acre of usable wood and divide by the density of the species, or use an average density of 38.1 pounds per cubic foot for northeastern hardwood forest types or 26.2 pounds per acre for coniferous forest types. Divide this amount by 90 cubic feet per cord to get cords per acre, or by 100 cubic feet to get cunits per acre.

Example: There are 10 tons per acre of hardwood material 3 inches and larger that can be used as an energy source.

10 tons/acre = 20,000 pounds.

20,000 pounds ÷ 38.1 pounds/foot^3 ÷ 90 feet^3 = 5.8 cords/acre.

20,000 pounds ÷ 38.1 pounds/foot^3 ÷ 100 feet^3 = 5.2 cunits/acre.

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APPENDIX V.
Similar Species

The tables presented can be used for species with similar crown characteristics:

For:	Use:
Virginia pine	Jack pine
Tamarack	Western larch (Brown *et al.* 1977)
Sugar maple	Red maple
Yellow birch	Paper birch
Balsam poplar	Quaking aspen

Freeman, Duane R.; Loomis, Robert M.; Roussopoulos, Peter J.
Handbook for predicting slash weight in the Northeast. Gen. Tech. Rep. NC-75. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1982. 23 p.

Tables are provided for estimating tree crown weights based on species and diameters (d.b.h.) for 10 conifer and 9 hardwood species or species groups of the North Central and Northeastern United States. Procedures are given for predicting slash weights resulting from: cutting timber, trampling during logging activities, and defect and breakage left on the site after cutting.

KEY WORDS: Fuel management, slash, debris prediction, forest fuels, tree biomass.

**United States
Department of
Agriculture**

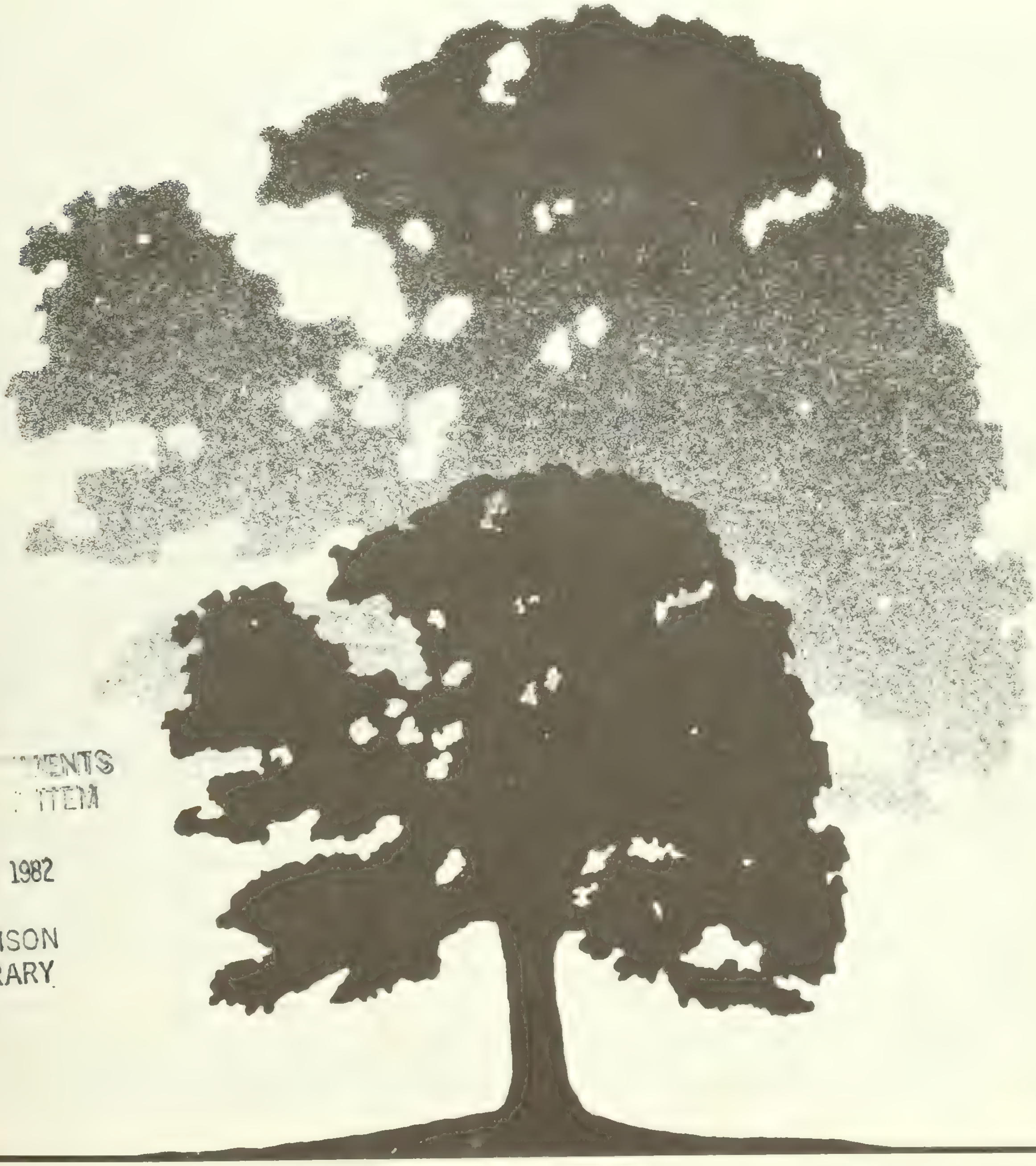
Forest
Service

North Central
Forest Experiment
Station

General Technical
Report **NC-76**

How to Estimate Weights of Northern Red Oak Crowns in a Stand

Robert M. Loomis and Richard W. Blank



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HOW TO ESTIMATE WEIGHTS OF NORTHERN RED OAK CROWNS IN A STAND

Robert M. Loomis, *Fire Management Scientist,*
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Tree crowns may become a significant forest fuel, particularly after logging operations, insect epidemics, high winds, or ice storms. To appraise potential fire behavior after cutting or other disturbances, a method has been developed[1] to estimate crown fuel weights in stands of northern red oak (*Quercus rubra* L.). The estimates should also be reasonably accurate for other black oak species and other "hard" hardwoods with similar crown form (such as hickory), and be usable throughout the eastern United States. The method can also be used to estimate fiber amounts.

ESTIMATING DRY WEIGHTS OF FOLIAGE AND BRANCHWOOD

To estimate weights of foliage and branchwood (including bark),[2] the "variable radius plot" technique is used. If a 10-factor prism is used, for example, each tree tallied represents 10 square feet of basal area (BA) per acre. The d.b.h. and crown ratio (CR) of each tallied tree must also be determined. (Crown ratio is the ratio of live crown length to total tree height expressed as a percentage.) From d.b.h., crown ratio, and basal area per acre represented, you can determine the weights of the following crown components:

- Dry weight of live branchwood by diameter class (table 1).
- Total dry weight of all live branchwood (table 2).
- Dry weight of dead branchwood by diameter class and total weight (table 3).
- Dry weight of foliage (table 4).
- Dry weight of bole sections between 1 and 3 inches in diameter (table 5).

Examples

The following examples show how to determine crown component weights, both in pounds per square foot of basal area and pounds per acre for the stand, from tables 1 through 5.[3]

First collect field data and combine tallied trees into groups by d.b.h. and crown ratio. Seven tallied trees are collected this way in the sample worksheets (figs. 1-4). Since the instrument used has a basal area factor of 10, multiply the number of tallied trees in a group by 10 to get the "square feet of basal area per acre represented" (e.g., 3 trees x 10 BAF = 30 square feet BA/acre). Note that "30" has been inserted in the proper column in figures 1-4.

---

[1] *Loomis, R. M.; Blank, R. W. Estimating northern red oak crown component weights in the Northeastern United States. Res. Pap. NC-194. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1981. 9 p.*

[2] *"Branchwood" and also "bolewood" as used in this report refer to both wood and bark.*

[3] *Any table value "per square foot of basal area" can be converted to "per tree" by multiplying the table value by the number of actual square feet of basal area contained by the tree. For example, a tree with a d.b.h. of 10 inches contains 0.55 square foot of basal area. Assume that the tree has a 50 percent crown ratio. Table 4 shows 27 pounds per square foot of basal area of foliage. Thus: 27 pounds per square foot of basal area x 0.55 square foot of basal area per tree = about 15 pounds of foliage per tree.*

Table 1.—*Dry weight of northern red oak live branchwood*[1] *by diameter class*

D.b.h. (inches)	Crown ratio[2] (percent)															
	20				30				40				50			
	0-¼	¼-1	1-3	3+[3]	0-¼	¼-1	1-3	3+	0-¼	¼-1	1-3	3+	0-¼	¼-1	1-3	3+
	Pounds per square foot of basal area															
1	18				18				18	16			18	18		
2	9	9			14	18			18	32			23	50		
3	8	16			12	33			16	53			20	65	14	
4	7	23			10	41	3		14	53	21		18	64	45	
5	7	29			10	40	17		12	51	39		16	62	69	
6	6	28	7		9	40	28		12	51	61		15	61	92	
7	6	27	12		9	37	37		12	49	75		14	60	120	
8	6	28	18		8	37	49		11	49	89		13	57	129	11
9	5	27	25		8	36	59		11	50	95	10	13	57	129	34
10	5	26	29		8	37	64	5	10	48	93	28	13	59	126	55
11	5	26	33		7	36	64	15	10	45	97	41	12	56	129	76
12	5	25	37	2	7	36	64	24	10	46	95	56	12	55	129	97
13	5	26	36	7	7	37	64	33	9	46	94	71	12	56	124	118
14	5	25	36	12	7	36	64	41	9	47	93	83	11	54	125	138
15	5	25	36	16	7	36	64	50	9	45	93	98	11	55	125	156
16	4	25	36	21	6	34	64	59	9	46	92	110	11	55	124	175
17	4	25	36	25	6	35	63	67	8	46	92	124	10	55	122	195
18	4	24	36	31	6	35	63	75	8	45	90	138	10	54	124	212
19	4	25	36	35	6	35	62	84	8	45	91	150	10	53	125	230
20	4	24	36	39	6	35	62	92	8	44	92	162	10	51	126	247
21	4	24	37	43	6	35	63	99	8	43	92	175	10	53	122	266
22	4	24	36	48	6	34	63	107	8	42	92	188	10	52	122	285
23	4	24	36	52	6	34	63	115	8	44	92	198	9	54	121	301
24	4	24	36	56	6	32	63	123	7	42	92	211	10	51	125	315
25	4	23	35	60	6	34	60	132	7	44	91	222	9	53	119	335

D.b.h. (inches)	Crown ratio[2] (percent)											
	60				70				80			
	0-¼	¼-1	1-3	3+	0-¼	¼-1	1-3	3+	0-¼	¼-1	1-3	3+
	Pounds per square foot of basal area											
1	37	18			37	37			37	37		
2	28	69			32	92	5		37	101	18	
3	22	75	33		26	86	55		31	94	79	
4	21	71	69		24	81	101		29	96	138	
5	20	72	110		23	81	147		26	88	191	
6	18	71	138		21	81	188		24	92	244	
7	17	71	165	3	20	79	206	23	23	90	239	49
8	16	69	163	34	19	77	198	66	22	86	241	97
9	16	68	161	66	18	77	199	104	21	86	240	143
10	15	66	161	95	18	77	198	137	20	86	233	191
11	15	65	164	120	17	76	198	171	20	83	233	233
12	14	64	163	148	17	73	199	207	19	85	232	275
13	14	65	162	174	16	73	194	242	18	86	228	319
14	14	65	157	201	16	74	195	273	18	79	234	357
15	13	66	157	227	15	73	194	306	17	84	225	399
16	13	65	155	253	15	72	192	340	16	82	229	435
17	13	63	158	275	15	69	195	370	16	79	232	472
18	12	62	160	298	14	74	190	400	17	75	234	511
19	12	60	161	323	14	71	191	432	16	80	227	550
20	12	63	156	347	14	67	191	463	16	75	227	589
21	11	61	156	372	14	70	191	490	15	79	226	622
22	11	64	156	392	14	66	190	523	16	72	235	655
23	11	59	155	419	13	69	189	550	15	76	223	699
24	11	62	153	439	13	72	186	576	15	80	219	731
25	11	58	158	460	13	66	192	603	14	72	226	765

---

[1] Includes bolewood less than 1 inch in diameter. Branchwood and bolewood include wood and bark.

[2] The ratio of live crown length to total tree height expressed as a percent.

[3] Due to rounding, the sum of the four diameter classes may not equal the total value given in table 2.

Table 2.—*Total dry weight of northern red oak live branchwood*[1]
(In pounds per square foot of basal area)

D.b.h. (inches)	Crown ratio[2] (percent)						
	20	30	40	50	60	70	80
1	18	18	37	37	55	73	92
2	18	32	50	73	96	124	151
3	24	45	69	100	132	169	204
4	30	56	88	126	160	206	264
5	35	67	103	147	198	249	308
6	41	76	122	168	229	290	357
7	45	86	135	191	254	326	400
8	52	95	149	212	284	361	444
9	57	104	165	233	310	396	489
10	60	114	178	253	337	429	530
11	65	123	192	273	364	462	570
12	69	131	206	292	388	495	610
13	74	140	219	310	413	526	650
14	79	148	232	329	438	557	687
15	82	156	245	347	462	588	726
16	87	164	257	365	486	619	763
17	91	172	269	382	509	649	799
18	95	179	282	400	533	678	837
19	99	187	294	418	556	708	872
20	103	195	306	434	578	736	907
21	107	203	318	451	601	765	943
22	111	210	330	468	623	793	978
23	115	218	341	485	645	821	1013
24	119	224	352	500	665	847	1045
25	122	231	364	516	687	874	1078

[1] Branchwood includes bolewood less than 1.0 inch in diameter. Branchwood and bolewood include wood and bark.

[2] Crown ratio is the ratio of live crown length to total tree height expressed as a percent.

Table 3.—*Dry weight of northern red oak dead branchwood*[1] *by diameter class and total weight*
(In pounds per square foot of basal area)

D.b.h. (inches)	Diameter class (inches)				
	0-¼	¼-1	1-3	3+	Total[2]
1	18.0	55			73
2	9.2	46			55
3	6.1	41			47
4	5.7	38			44
5	4.4	37			41
6	3.6	35	0.5		39
7	3.0	23	12		37
8	2.6	16	17		37
9	2.0	12	21	0.5	34
10	1.6	8.8	22	1.6	33
11	1.5	6.7	23	2.6	33
12	1.3	5.1	22	3.6	32
13	1.1	3.9	23	4.0	31
14	0.9	3.2	22	4.6	31
15	0.8	2.8	22	4.8	30
16	0.7	2.2	21	5.3	29
17	0.6	1.7	21	5.5	29
18	0.6	1.5	21	5.7	28
19	0.6	1.3	20	6.1	28
20	0.5	1.1	20	6.0	27
21	0.5	1.0	20	5.8	27
22	0.5	0.9	19	6.1	27
23	0.5	0.8	19	6.2	27
24	0.5	0.8	19	6.4	26
25	0.5	0.8	18	6.2	26

[1] Dead branchwood includes material from both within and below the live crown. Branchwood refers to both wood and bark.

[2] Due to mathematical rounding, the sum of the four diameter classes may not always equal the total figures.

FINDING THE DRY WEIGHT OF LIVE BRANCHWOOD BY DIAMETER CLASS

1. In table 1 use the appropriate d.b.h. and crown ratio to obtain dry weight of live branchwood by diameter class per square foot of basal area. (For example, in the worksheet in figure 1, a 12-inch d.b.h. and 50-percent crown ratio yield 12 pounds of live branchwood per square foot of basal area for the 0-1/4-inch diameter class.)
2. Multiply the pounds per square foot of basal area by the square feet of basal area per acre represented to find the pounds in each diameter class per acre (e.g., 12 pounds/square foot BA x 30 square feet BA/acre = 360 pounds per acre).
3. Repeat the process for the other diameter classes and the other tree groups from the field tally.

FINDING THE TOTAL DRY WEIGHT OF LIVE BRANCHWOOD

1. In table 2, use the appropriate d.b.h. and crown ratio to find total dry weight per square foot of basal area. The worksheet in figure 2 shows that a 12-inch d.b.h. and 50-percent CR yields 292 pounds/square foot of basal area.
2. Multiply the pounds per square foot of basal area by the square feet of basal area per acre represented to get the total dry weight per acre for each tree group. (Note in figure 2 that 292 pounds/square foot BA x 30 square feet BA/acre = 8,760 pounds/acre.)
3. Repeat the process for the other tree groups from the field tally.

Table 4.—*Dry weight of northern red oak foliage*

(In pounds per square foot of basal area)

D.B.h. (inches)	Crown ratio[1] (percent)						
	20	30	40	50	60	70	80
1	37	55	55	73	92	92	110
2	23	37	46	55	64	73	83
3	20	29	37	45	53	61	69
4	18	26	33	40	47	54	61
5	17	23	30	37	43	49	55
6	15	22	28	34	40	46	51
7	15	21	26	32	37	41	49
8	14	19	25	32	34	40	46
9	13	19	23	29	34	38	43
10	12	18	22	27	31	37	40
11	12	17	21	26	30	35	39
12	12	17	20	25	29	34	38
13	11	16	21	25	28	33	37
14	11	15	20	24	28	32	36
15	11	15	19	23	27	31	35
16	10	14	19	22	26	30	34
17	10	14	18	22	25	29	33
18	10	13	17	21	25	29	32
19	10	14	17	21	24	28	32
20	9	13	17	21	24	27	31
21	9	13	17	20	24	27	30
22	9	13	16	20	23	27	30
23	9	12	16	19	23	26	29
24	9	12	16	19	22	25	29
25	9	12	16	19	22	25	28

[1] Crown ratio is the ratio of live crown length to total tree height ex- ressed as a percent.

Table 5.—*Dry weight of bole sections from 1 to 3 inches in diameter*

D.b.h. (inches)	Bole section
	Pounds per square foot of basal area
1	367
2	504
3	244
4	149
5	95
6	66
7	49
8	37
9	29
10	22
11	18
12	15
13	12
14	10
15	8.2
16	7.2
17	6.3
18	5.1
19	4.6
20	3.7
21	3.3
22	3.0
23	2.4
24	2.2
25	2.1

FINDING THE DRY WEIGHT OF DEAD BRANCHWOOD BY FOUR DIAMETER CLASSES AND TOTAL WEIGHT

. To get the dry weight of dead branchwood in the various branch diameter classes, find the d.b.h. of the tallied tree groups in table 3. (In the worksheet in figure 3, 12-inch d.b.h. at 0-1/4-inch = 1.3 pounds.)

. To get the dry weight of dead branchwood per acre for each diameter class, multiply the pounds per square foot of basal area by square feet of basal area per acre represented (e.g., 1.3 pounds/square foot BA x 30 square feet BA/acre = 39 pounds acre).

. Repeat the process for the other tree groups.

. To get the total dry weight of dead branchwood for all diameter classes per square foot of basal area, consult table 3. Obtain the total dry weight per acre by multiplying the total pounds per square foot of basal area by the square feet of basal area per acre represented (e.g., using 12-inch d.b.h., 32 pounds/square foot of basal area x 30 square feet BA/acre = 960 pounds/acre).

5. Repeat the process for the other tree groups.

FINDING THE DRY WEIGHT OF FOLIAGE

1. To get the dry weight of foliage, use the d.b.h. and crown ratios in table 4. (See the worksheet in figure 4, using 12-inch d.b.h. and 50-percent CR. The pounds of foliage per square foot of basal area is 25.)
2. Multiply the pounds per square foot of basal area by the square feet of basal area per acre represented to get the total pounds of foliage per acre. (Note in figure 4 that 25 pounds/square foot BA x 30 square feet BA/acre = 750 pounds per acre.)
3. Repeat the process for the other tree groups from the field tally.

Sample plot no.	Trees	D.b.h.	Crown ratio	Basal area/acre represented	Weight of live branchwood by diameter class (inches)							
					0-1/4		1/4-1		1-3		3+	
					Per square foot of basal area	Per acre	Per square foot of basal area	Per acre	Per square foot of basal area	Per acre	Per square foot of basal area	Per acre
	No	In	Percent	Ft^2	-Pounds-							
1	3	12	50	30	12	360	55	1,650	129	3,870	97	2,910
	1	14	60	10	14	140	65	650	157	1,570	201	2,010
	3	10	40	30	10	300	48	1,440	93	2,790	28	840
Total:	7			70		800		3,740		8,230		5,760

Figure 1.—*Sample worksheet for instrument with basal area factor 10 to determine weight of live branchwood by diameter class (from table 1).*

Sample plot no.	Trees	D.b.h.	Crown ratio	Basal area/acre represented	Weight of live branchwood	
					Per square foot of basal area	Per acre
	No	In	Percent	Ft^2	-Pounds-	
1	3	12	50	30	292	8,760
	1	14	60	10	438	4,380
	3	10	40	30	178	5,340
Total:	7			70		18,480

Figure 2.—*Sample worksheet for instrument with basal area factor 10 to determine total weight of live branchwood (from table 2).*

Sample plot no.	Trees	D.b.h.	Crown ratio	Basal area/acre represented	Weight of dead branchwood by diameter class (inches)									
					0-1/4		1/4-1		1-3		3+		Total	
					Per square foot of basal area	Per acre	Per square foot of basal area	Per acre	Per square foot of basal area	Per acre	Per square foot of basal area	Per acre	Per square foot of basal area	Per acre
	No	In	Percent	Ft^2	-Pounds-									
1	3	12	50	30	1.3	39	5.1	153	22	660	3.6	108	32	960
	1	14	60	10	0.9	9	3.2	32	22	220	4.6	46	31	310
	3	10	40	30	1.6	48	8.8	264	22	660	1.6	48	33	990
Total:	7			70		96		449		1,540		202		2,260

Figure 3.—*Sample worksheet for instrument with basal area factor 10 to determine dry weight of dead branchwood by four diameter classes and total weight (from table 3).*

					Weight of Foliage		Weight of Bole Section 1 to 3 inches in diameter	
Sample plot no.	Trees	D.b.h.	Crown ratio	Basal area/acre represented	Per square foot of basal area	Per acre	Per square foot of basal area	Per acre
	No	*In*	*Percent*	*Ft²*	- - - - - - - - - *Pounds*	- - - - - - - - - -		
1	3	12	50	30	25	750	15	450
	1	14	60	10	28	280	10	100
	3	10	40	30	22	660	22	660
Total:	7			70		1,690		1,210

Figure 4.—*Sample worksheet for instrument with basal area factor 10 for determining dry weight of foliage and of bole sections from 1 to 3 inches in diameter (from tables 4 and 5).*

FINDING THE DRY WEIGHT OF BOLE SECTIONS FROM 1 TO 3 INCHES IN DIAMETER

1. To get the dry weight of bole sections, use the d.b.h. of the tallied tree groups in table 5. (Again, see the worksheet in figure 4. Using 12-inch d.b.h., the weight of the bole section is about 15 pounds/square foot of BA.)
2. Multiply the weight per square foot of basal area by the square feet of basal area per acre represented to get the pounds of bole sections per acre (e.g., 15 pounds/square foot BA x 30 square feet BA/acre = 450 pounds/acre).
3. Repeat process for the other tree groups.

Loomis, Robert M.; Blank, Richard W.
How to estimate weights of northern red oak crowns in a stand. Gen. Tech. Rep. NC-76. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1982. 8 p.

Describes how to estimate the weights of northern red oak and other hardwood tree crowns that could become fuels after storms, logging, or insect epidemics. Presents tables, sample worksheets, and examples.

KEY WORDS: Forest fuels, fire behavior, crown fuels, foliage weight, branchwood weight.

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Stereo Photos for Evaluating Jack Pine Slash Fuels

Richard W. Blank

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STEREO PHOTOS FOR EVALUATING JACK PINE SLASH FUELS

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Jack pine (*Pinus banksiana* Lamb.) is one of the ost fire-prone communities in the Northeastern and orth Central States. Land managers who prescribe re in jack pine forests must recognize the imporance of various fuels in order to predict fire behavior nd plan for fire control and smoke management.

Where logging has taken place in the jack pine ommunity, the most important fuel component is lash or logging residue. The size, depth, and disribution of jack pine slash strongly influence fire ehavior. The small sizes are particularly important n the Lake States because residue from pulpwood perations tends to be under 3 inches in diameter.

Managers also need to know about the other fuels n the jack pine community—litter, duff, sedges, rasses, forbs, shrubs, and trees. In Michigan, sedges[1] *Carex* spp.) are often a major carrier of surface fire.

The purpose of the present photo series is to proide land managers with fuel amounts, size classes, eights, and vertical distributions so that they can ake fuel management plans and decisions in cuover jack pine without resorting to time-consuming nd expensive sampling. The photos should also be elpful to those involved in smoke management or re training.

Since 1976, fire managers in the western United tates have used photographs (Maxwell and Ward 976a, 1976b, 1979) and stereo photographs (Ryan nd Johnson 1979) in conjunction with the planar tercept method of fuel sampling (Brown 1974) for esidue management. In Pennsylvania a photo series r quantifying hardwood logging residue is being epared.[2]

METHODS

To represent a useful range of fuel conditions, we selected photo points on the basis of slash age, loading, continuity, and distribution. (Areas that were windrowed, roller chopped, or used as landings were avoided.) We chose seven areas of 1-year-old slash with loadings of 2, 8, 10, 16, 23, 29, and 31 tons/acre and two 3-year-old areas with loadings of 12 and 17 tons/acre. We had intended to burn all areas, document burning conditions, and remeasure to provide fuel amounts left after burning. At the time that this photo series was completed, however, only the 3-year-old, 17-tons/acre plot had been burned. Post burning appearance and data are given for the burned plot in Photo 10.

We modified Brown's planar intercept sampling method to keep all randomly selected sampling planes within the camera's field of view. To emphasize the small fuels, we established a minimum of 18 sample points in the 0- to 1-inch size class. Each of these sampling planes was 8 feet long. This method ensured that the results were within ±15 percent of the true value.

For each plot, we laid out a triangular sampling area measuring 160 feet along the sides and approximately 75 feet along the base (fig. 1). Each sampling area enclosed about 1/8 of an acre. The triangular area was truncated at the point where it was 8 feet wide, the nearest point in the camera's view. The camera was positioned 10 feet beyond that

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[1] *Sedges and grasses will be referred to as "grasses" this paper.*

[2] *Wilcox, Fred. Photo series for quantifying forest residues in the Pennsylvania hardwoods. Unpublished manuscript on file at the Pennsylvania Bureau of Forestry, Harrisburg, Pennsylvania.*

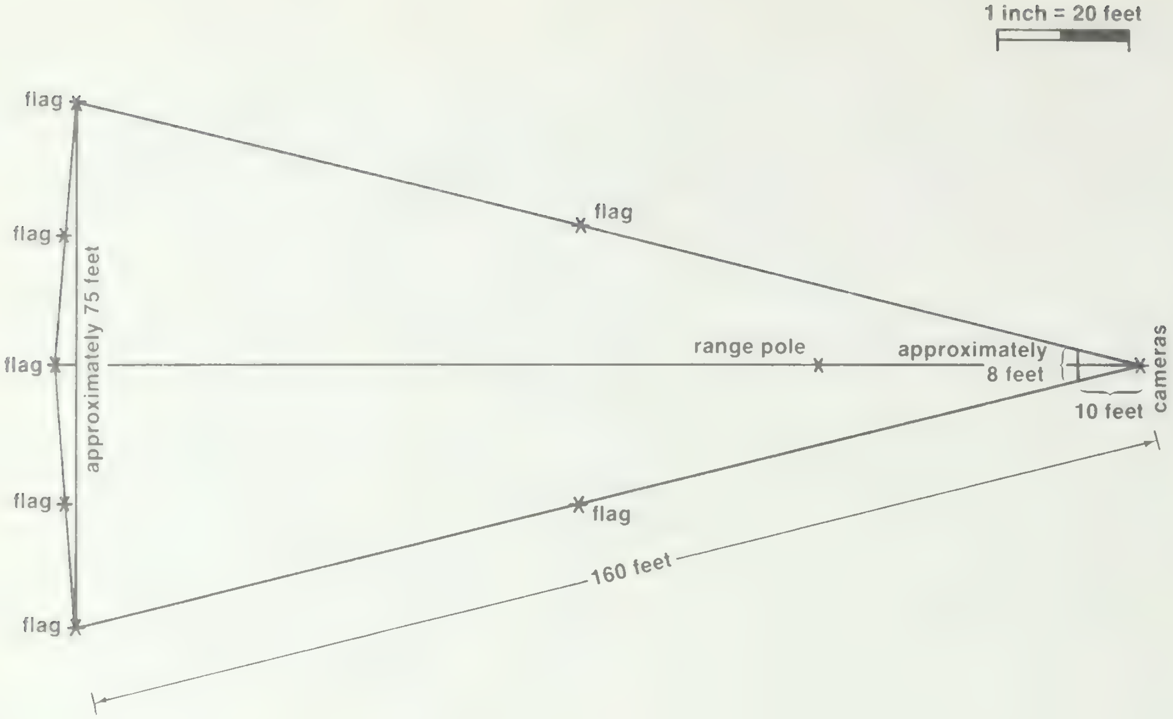

Figure 1.—*Plot sampling area and camera's field of view.*

point, 9 feet off the ground. (It did not view the first 10 feet.) To delineate the field of view,[3] we set flags at 85 feet along the sides and on the base 160 feet from the camera. An 8-foot range pole, marked at 1-foot intervals, was centered in the field of view 50 feet from the camera lens to show perspective. To obtain the stereo pairs, we used two cameras set 12 inches apart.

We randomly selected at least five 1/4 mil-acre subsamples within the 1/8-acre sampling area and clipped, sorted, and measured grasses, forbs, and shrubs. Litter and duff depth measurements and samples were taken from the center of each 1/4 mil-acre plot. All samples were oven-dried at 105°C for 24 hours and then weighed.

The prescribed burn on the plot with 3-year-ol slash, 17 tons/acre was conducted by crews from th Michigan Department of Natural Resources (DNR We sampled within 24 hours of the burn, using th same method as used for pre-burn sampling. Timbe stand and logging information was obtained from th Michigan DNR and U.S. Forest Service District O fices.

HOW TO USE THIS PHOTO SERIES

This photo series can be used in the field to obtai a quick estimate of the characteristics of jack pin slash and other fuels.

1. If the pre-logging basal area is available, use th following equation (Roussopoulos and Johnso 1975) to get a rough idea of the slash loading o the area of interest:

Pre-logging basal area (sq ft/acre) x 0.15 = slas loading (tons/acre).

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[3] *The field of view and sampling method are approximately the same as suggested by the U.S. Department of Agriculture Forest Service, 1974, National Fuel Preliminary Draft, 27 p., on file at U.S. Department of Agriculture Forest Service, Washington, D.C.*

Using this slash loading figure, and the age of the slash (either 1 or 3 years), turn to the photo illustrating the same slash age and loading. This photo should show about what you see in your area.

If no pre-logging basal area is available, choose the photo that most closely illustrates what you see on the ground. Look at the depth of the slash and height of the other fuels on the photo. They should roughly approximate the heights and depths on the ground.

2. To double check, use a pair of stereo-glasses and examine the stereo photos to determine more closely the heights and depths of the slash and other fuels to see that they roughly match the area you are in.
3. Once you have matched the area in the field with the photos, you can read from the corresponding data sheet the amount per acre of the various sizes of slash and of other fuels—grasses, litter, etc. You can also find the heights and depths of slash and the other fuels. These may be usable in fire behavior equations.
4. The values, of course, are simply estimates; they are not exact. Especially variable are the fuel loadings other than slash. For greater accuracy you would have to make field measurements.
5. The stand information and method of harvest given on the data sheets may also be helpful in matching a photo with what you see on the ground.

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Data sheet 1.—**Approximate fuel amounts in areas similar to Photo 1.**

Fuels	Tons/acre	Height or depth
		Inches
Slash		
Branches		
0.0 -0.25	0.5	
0.26-1.0	1.0	
1.01-3.0	0.2	
3.0+	—	
Needles	0.3	
Subtotal	2.0	(Total weight lies within 1 foot of ground)
Grasses	0.4	7.0
Forbs	<0.05	4.0
Shrubs	0.4	7.0
Litter	2.8	0.4
Duff	6.8	0.4
Subtotal	10.4	
Grand Total Fuel Loading	12.4	

Location and Date: Sec 22, T25N,R1W, Mio District, Huron-Manistee National Forest; June 1979.

Stand Information: 50-year-old jack pine with scattered red oaks. Site index for jack pine was 45; basal area 30 square feet/acre; average volume 1.6 cords/acre. Photo was taken from same point as Photo No. 2 (1-year-old, 8 tons/acre) after almost all 1-inch diameter or larger slash had been removed.

Method of Harvest: Feller-buncher.

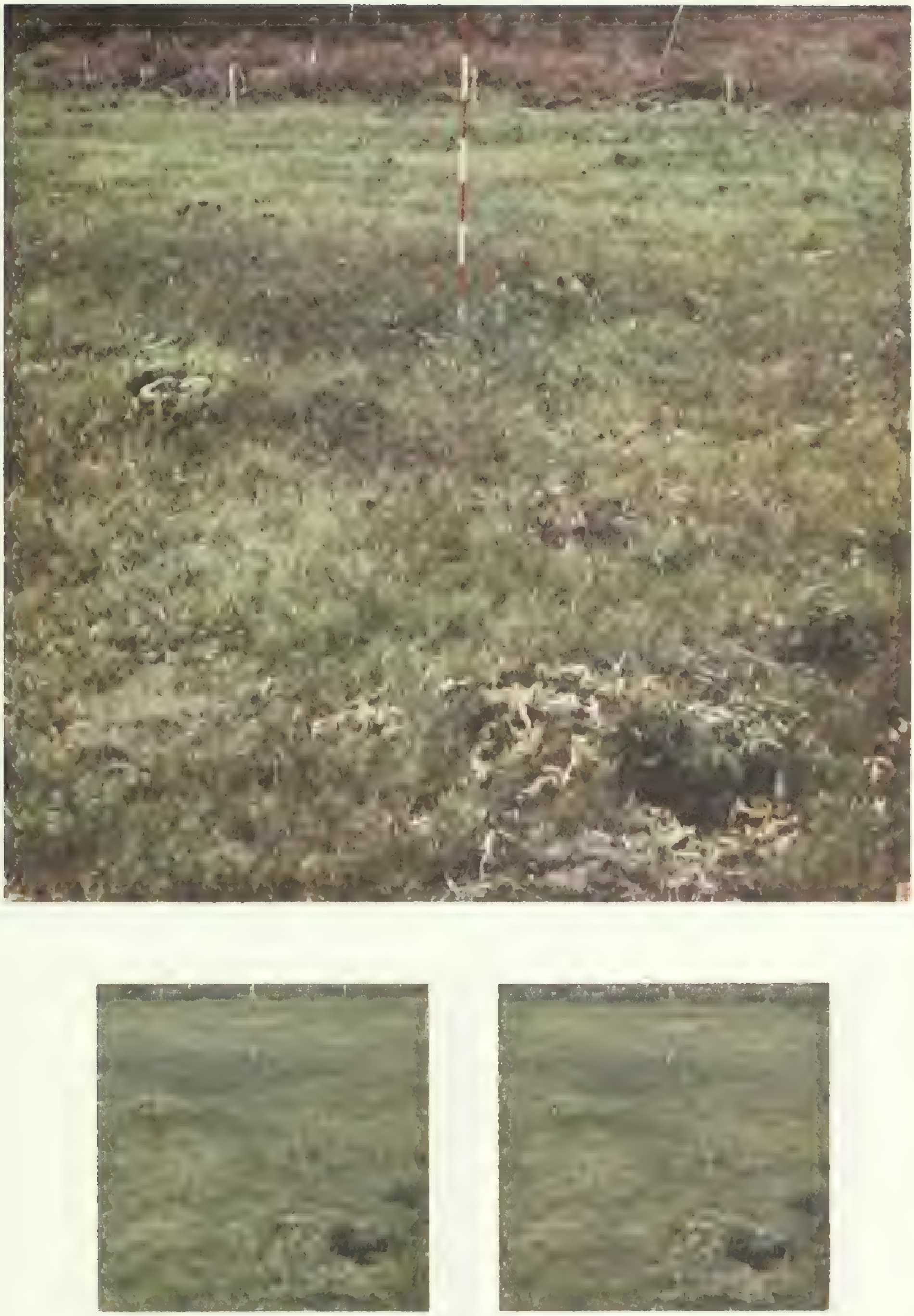

Photo 1.—*One-year-old slash, 2 tons/acre.*

Data sheet 2.—**Approximate fuel amounts in areas similar to Photo 2.**

Fuels	Tons/acre	Height or depth
		Inches
Slash		
Branches		
0.0 -0.25	1.3	
0.26-1.0	1.0	
1.01-3.0	2.1	
3.0+	2.9	
Needles	0.6	
Subtotal	7.9[1]	
Grasses	0.4	7.0
Forbs	<0.05	4.0
Shrubs	0.4	7.0
Litter	2.8	0.4
Duff	6.8	0.4
Subtotal	10.4	
Grand Total Fuel Loading	18.3	

[1] Vertical distribution of slash:

Height (feet)	Tons/acre
0-1	7.5
1-2	0.4

Location and Date: Sec 22, T25N,R1W, Mio District, Huron-Manistee National Forest; June 1979.

Stand Information: 50-year-old jack pine with scattered red oaks. Site index for jack pine was 45; basal area 30 square feet/acre; average volume 1.6 cords/acre.

Method of Harvest: Feller-buncher.

Time of Harvest: Winter, 1978-1979.

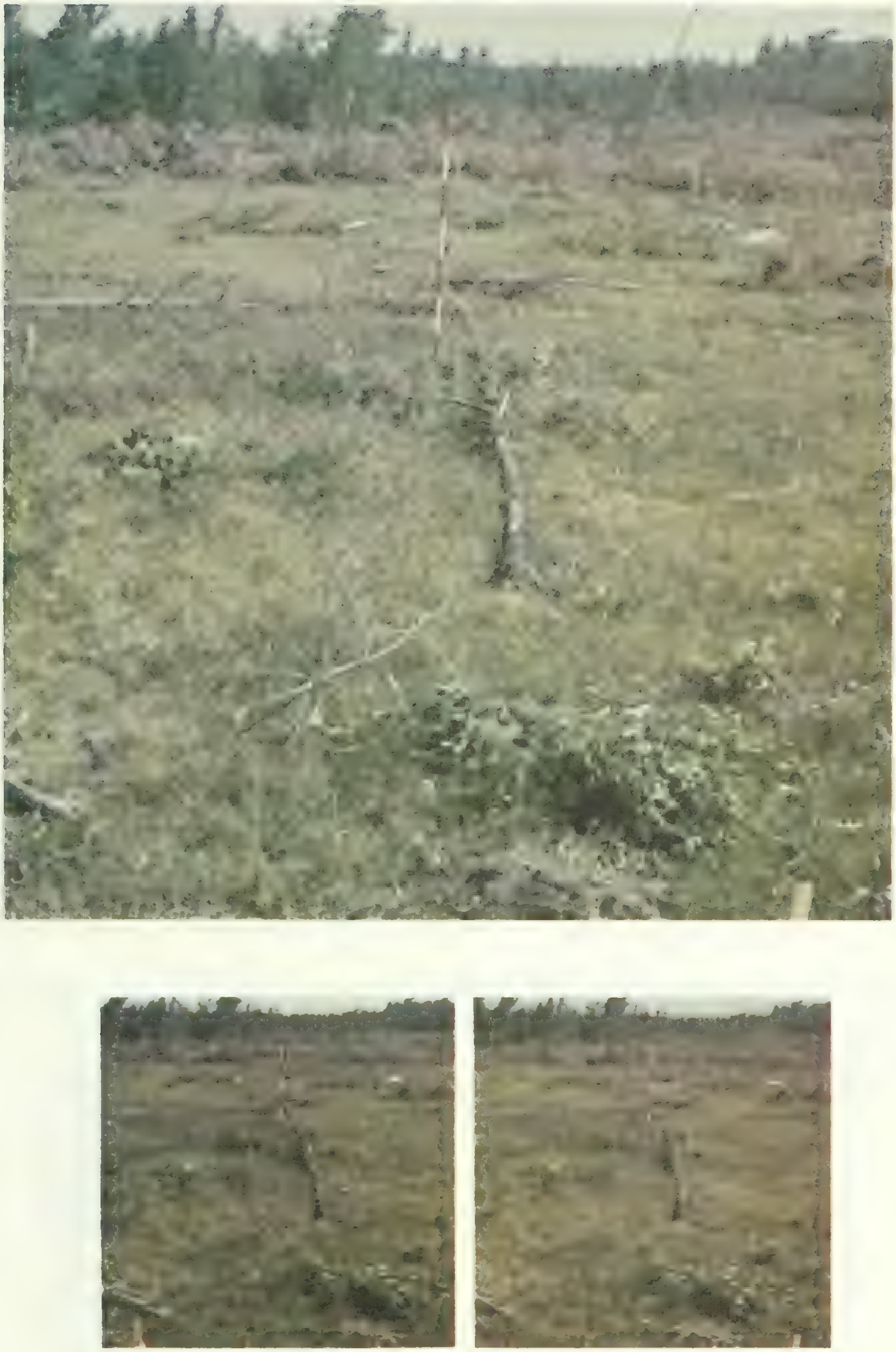

Photo 2.—*One-year-old slash, 8 tons/acre.*

Data sheet 3.— **Approximate fuel amounts in areas similar to Photo 3.**

Fuels	Tons/acre	Height or depth
		Inches
Slash		
Branches		
0.0 -0.25	1.4	
0.26-1.0	1.6	
1.01-3.0	2.5	
3.0+	4.2	
Needles	0.7	
Subtotal	10.4[1]	
Grasses	0.2	7.0
Forbs	—	—
Shrubs	0.8	6.0
Litter	6.3	0.7
Duff	4.2	0.3
Subtotal	11.5	
Grand Total Fuel Loading	21.9	

[1] Vertical distribution of slash:

Height (feet)	Tons/acre
0-1	10.4

Location and Date: Sec 22, T25N,R1W, Mio District, Huron-Manistee National Forest; July 1979.

Stand Information: 50-year-old jack pine with scattered red oaks. Site index for jack pine was 45; basal area 30 square feet/acre; average volume 1.6 cords/acre.

Method of Harvest: Feller-buncher.

Time of Harvest: Winter, 1978-1979.

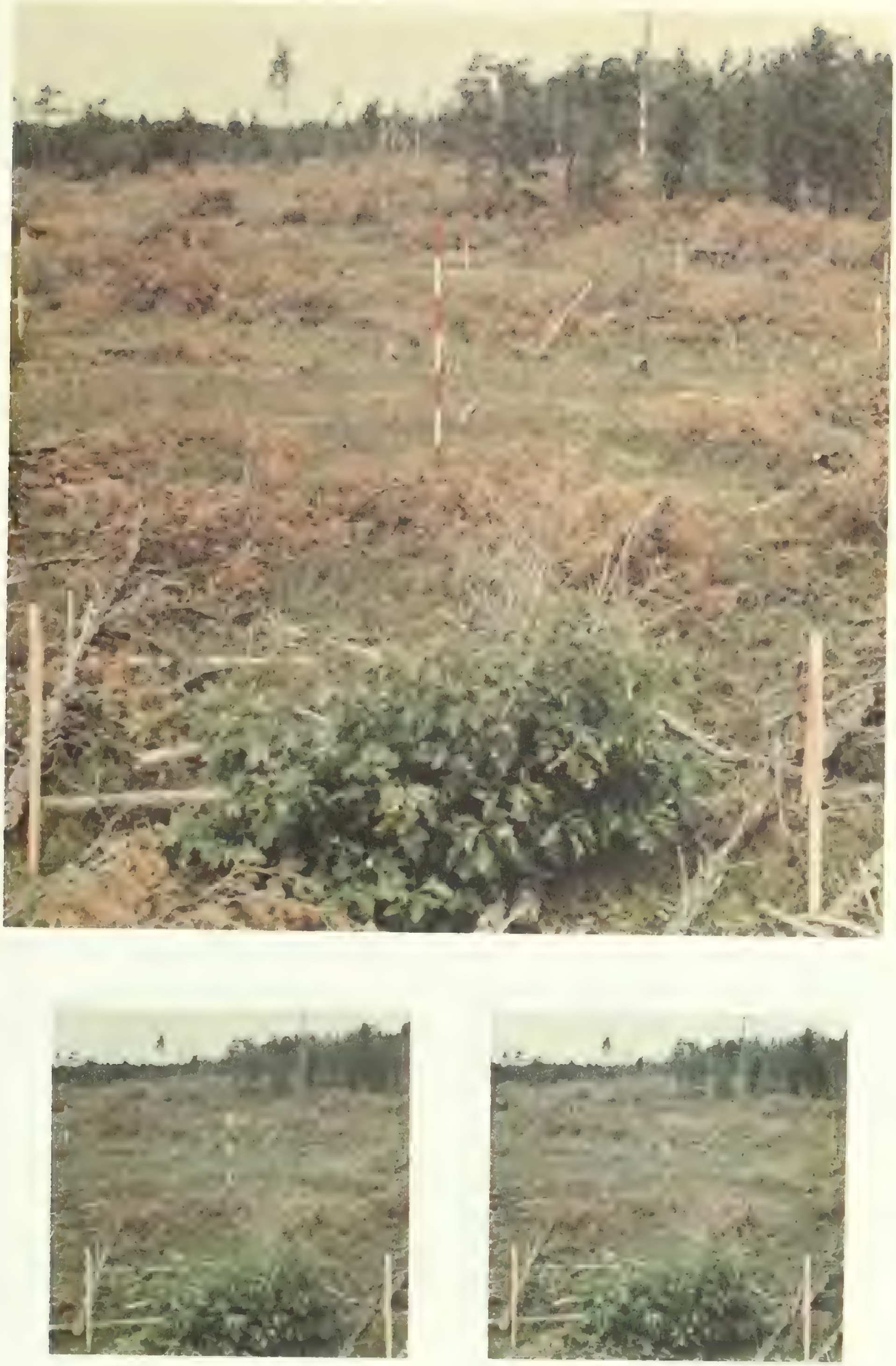

Photo 3.—*One-year-old slash, 10 tons/acre.*

Data sheet 4.—**Approximate fuel amounts in areas similar to Photo 4.**

Fuels	Tons/acre	Height or depth
		Inches
Slash		
Branches		
0.0 -0.25	2.8	
0.26-1.0	3.7	
1.01-3.0	6.3	
3.0 +	0.6	
Needles	2.4	
Subtotal	15.8[1]	
Grasses	0.1	9.0
Forbs	—	—
Shrubs	<0.05	6.0
Litter	6.0	0.7
Duff	9.0	0.4
Subtotal	15.1	
Grand Total Fuel Loading	30.9	

[1] Vertical distribution of slash:

Height (feet)	Tons/acre
0-1	14.5
1-2	1.1
2-3	0.2

Location and Date: Sec 30, T25N,R4W, Roscommon Forest area, Michigan Department of Natural Resources; September 1980.

Stand Information: 50-year-old jack pine. Site index for jack pine was 50; basal area 180 square feet/acre; average volume 14 cords/acre.

Method of Harvest: Feller-buncher.

Time of Harvest: Winter and Spring, 1979.

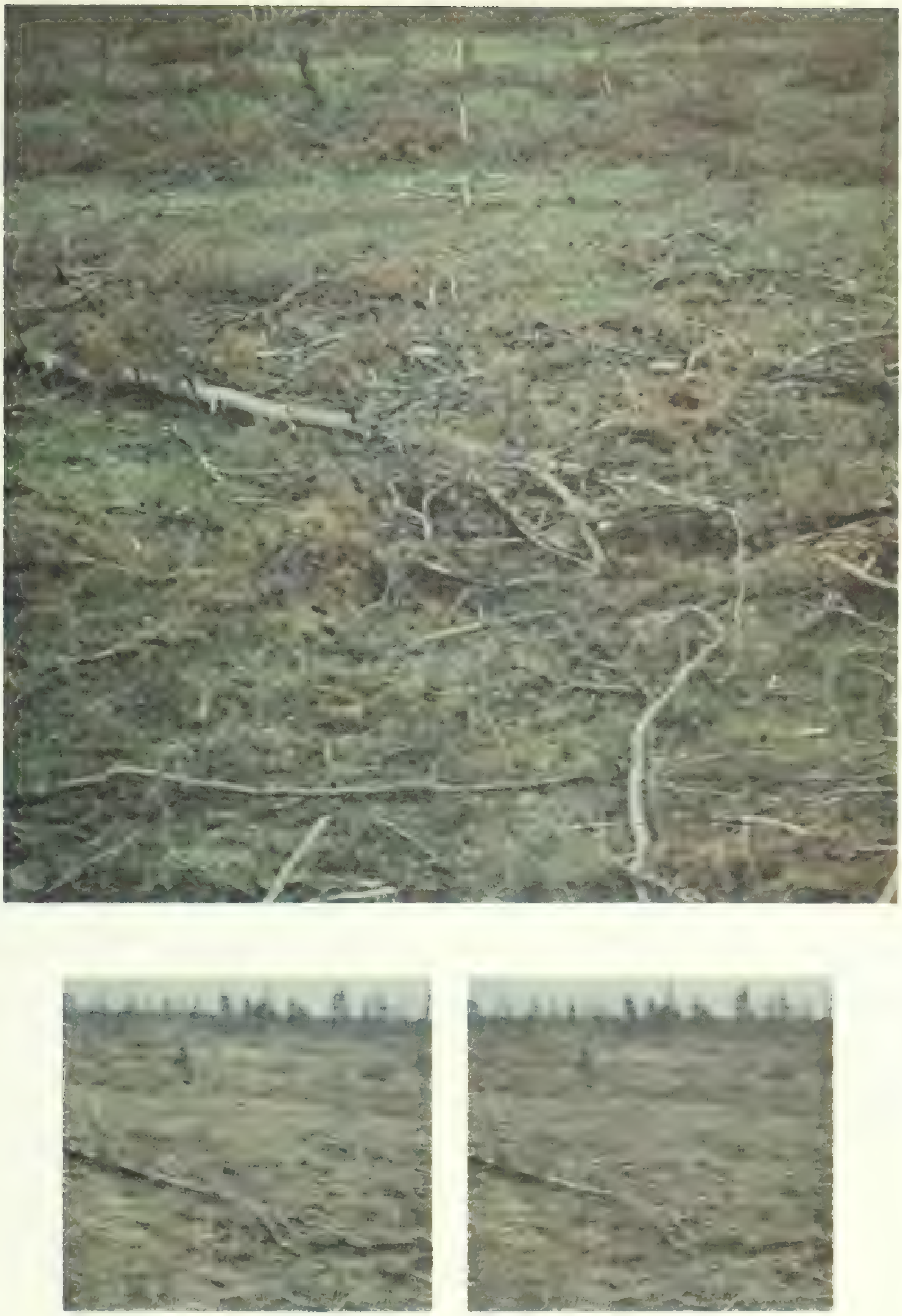

Photo 4.—*One-year-old slash, 16 tons/acre.*

Data sheet 5.—**Approximate fuel amounts in areas similar to Photo 5.**

Fuels	Tons/acre	Height or depth
		Inches
Slash		
Branches		
0.0 -0.25	2.8	
0.26-1.0	6.6	
1.01-3.0	6.0	
3.0 +	5.7	
Needles	1.7	
Subtotal	22.8[1]	
Grasses	<0.05	5.0
Forbs	—	—
Shrubs	—	—
Litter	3.7	0.3
Duff	12.0	0.5
Subtotal	15.7	
Grand Total Fuel Loading	38.5	

[1] Vertical distribution of slash:

Height (feet)	Tons/acre
0-1	22.0
1-2	0.7
2-3	0.1

Location and Date: Sec 22, T22N,R1W, Cadillac District, Huron-Manistee National Forest; September 1979.

Stand Information: 40-year-old jack pine plantation. Site index for jack pine was 50; basal area 170 square feet/acre; average volume 23 cords/acre. This was part of a 168-acre plantation that was ice-damaged.

Method of Harvest: Feller-buncher and chain saw.

Time of Harvest: Winter and Spring, 1978-1979.

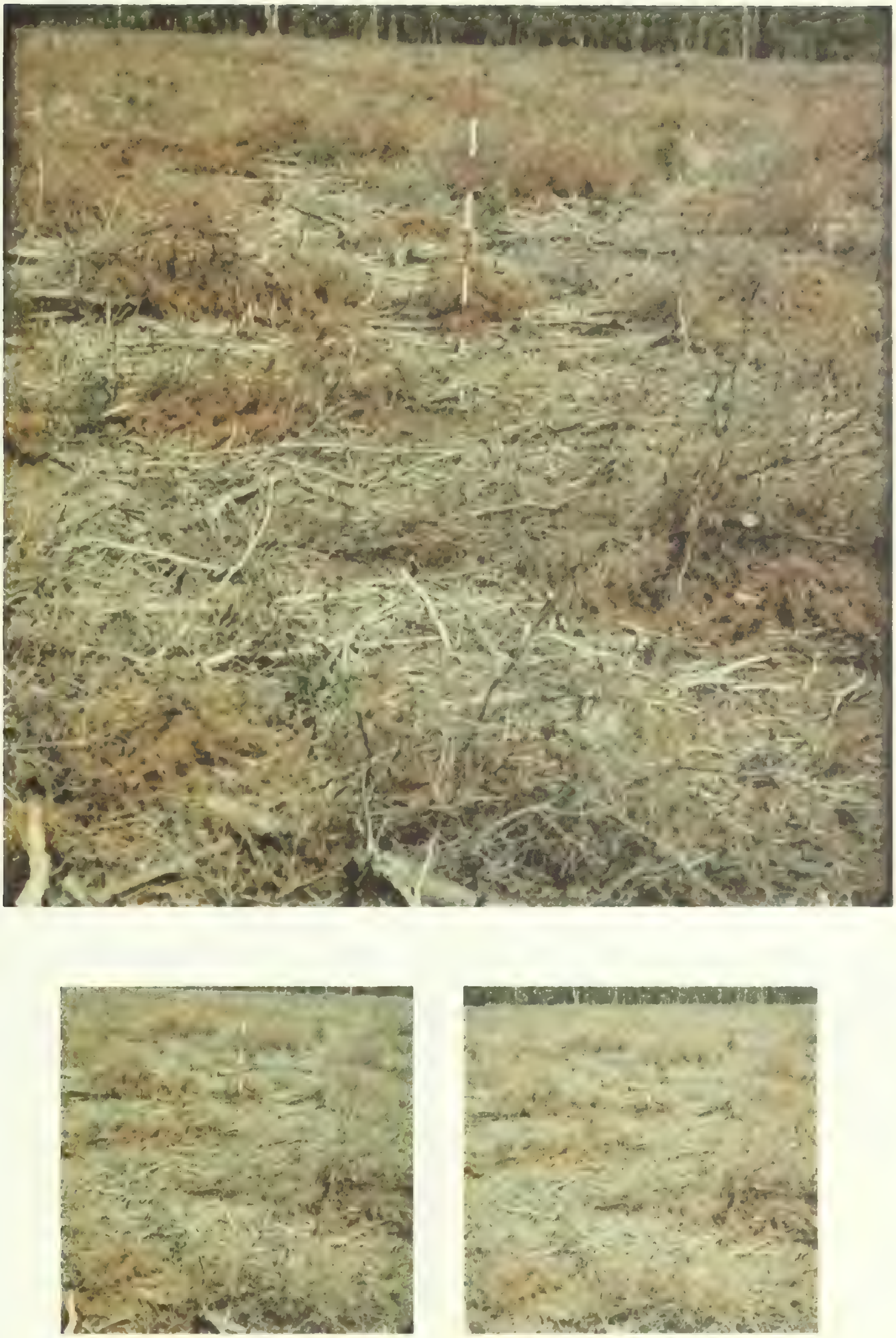

Photo 5.—*One-year-old slash, 23 tons/acre.*

Data sheet 6.—**Approximate fuel amounts in areas similar to Photo 6.**

Fuels	Tons/acre	Height or depth
		Inches
Slash		
Branches		
0.0 -0.25	4.7	
0.26-1.0	8.8	
1.01-3.0	7.0	
3.0+	5.5	
Needles	2.8	
Subtotal	28.8[1]	
Grasses	—	—
Forbs	—	—
Shrubs	—	—
Litter	3.1	0.3
Duff	14.6	0.9
Subtotal	17.7	
Grand Total Fuel Loading	46.5	

[1] Vertical distribution of slash:

Height (feet)	Tons/acre
0-1	26.6
1-2	2.2
2-3	<0.05
3-4	<0.05

Location and Date: Sec 22, T22N,R1W, Cadillac District, Huron-Manistee National Forest; September 1979.

Stand Information: 40-year-old jack pine plantation. Site index for jack pine was 50; basal area 170 square feet/acre; average volume 23 cords/acre. This was part of a 168-acre plantation that was ice-damaged.

Method of Harvest: Feller-buncher and chain saw.

Time of Harvest: Winter and Spring, 1978-1979.

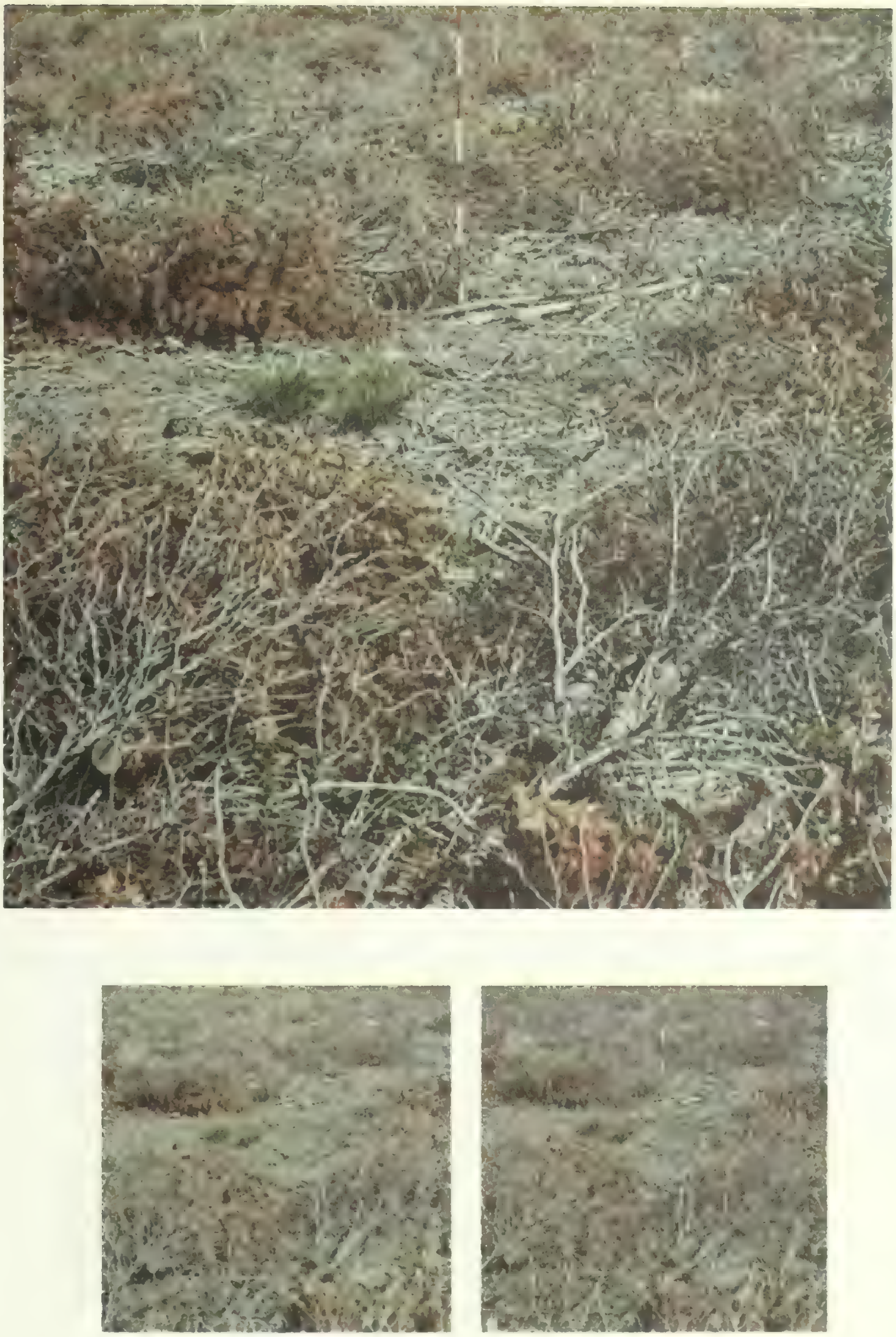

Photo 6.—*One-year-old slash, 29 tons/acre.*

Data sheet 7.—**Approximate fuel amounts in areas similar to Photo 7.**

Fuels	Tons/acre	Height or depth
		Inches
Slash		
Branches		
0.0 -0.25	3.2	
0.26-1.0	9.9	
1.01-3.0	6.2	
3.0+	9.8	
Needles	2.0	
Subtotal	31.1[1]	
Grasses	0.1	5.0
Forbs	—	—
Shrubs	—	—
Litter	2.1	0.3
Duff	9.8	0.5
Subtotal	12.0	
Grand Total Fuel Loading	43.1	

[1] Vertical distribution for slash:

Height (feet)	Tons/acre
0-1	26.8
1-2	3.4
2-3	0.7
3-4	0.1

Location and Date: Sec 22, T22N,R1W, Cadillac District, Huron-Manistee National Forest; August 1979.

Stand Information: 40-year-old jack pine plantation. Site index for jack pine was 50; basal area 170 square feet/acre; average volume 23 cords/acre. This was part of a 168-acre plantation that was ice-damaged.

Method of Harvest: Feller-buncher and chain saw.

Time of Harvest: Winter and Spring, 1978-1979.

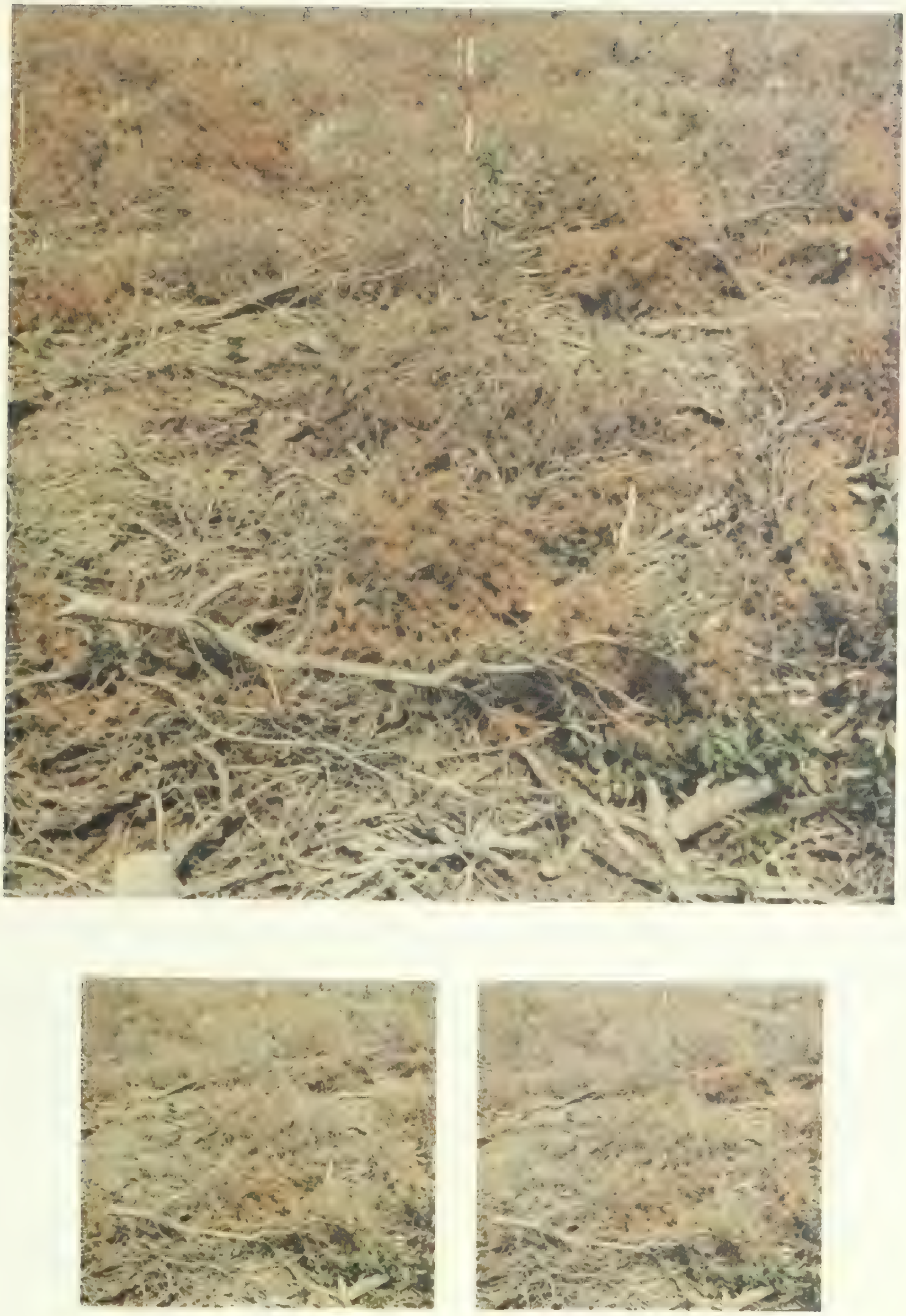

Photo 7.—*One-year-old slash, 31 tons/acre.*

Data sheet 8.—**Approximate fuel amounts in areas similar to Photo 8.**

Fuels	Tons/acre	Height or depth
		Inches
Slash		
Branches		
0.0 -0.25	0.9	
0.26-1.0	3.2	
1.01-3.0	5.5	
3.0+	2.1	
Needles	0.1	
Subtotal	11.8[1]	
Grasses	0.5	8.0
Forbs	—	—
Shrubs	0.1	5.0
Litter	4.5	0.4
Duff	9.3	0.5
Subtotal	14.4	
Grand Total Fuel Loading	26.2	

[1] Vertical distribution of slash:

Height (feet)	Tons/acre
0-1	11.5
1-2	0.3

Location and Date: Sec 8, T24N,R2W, Roscommon Forest area, Michigan Department of Natural Resources; August 1979.

Stand Information: 46-year-old jack pine with scattered red oaks. Site index for jack pine was 50; basal area 180 square feet/acre. After logging, firewood was taken from tops resulting in a low loading for slash greater than 3 inches in diameter.

Method of Harvest: Feller-buncher and chain saw.

Time of Harvest: 1976.

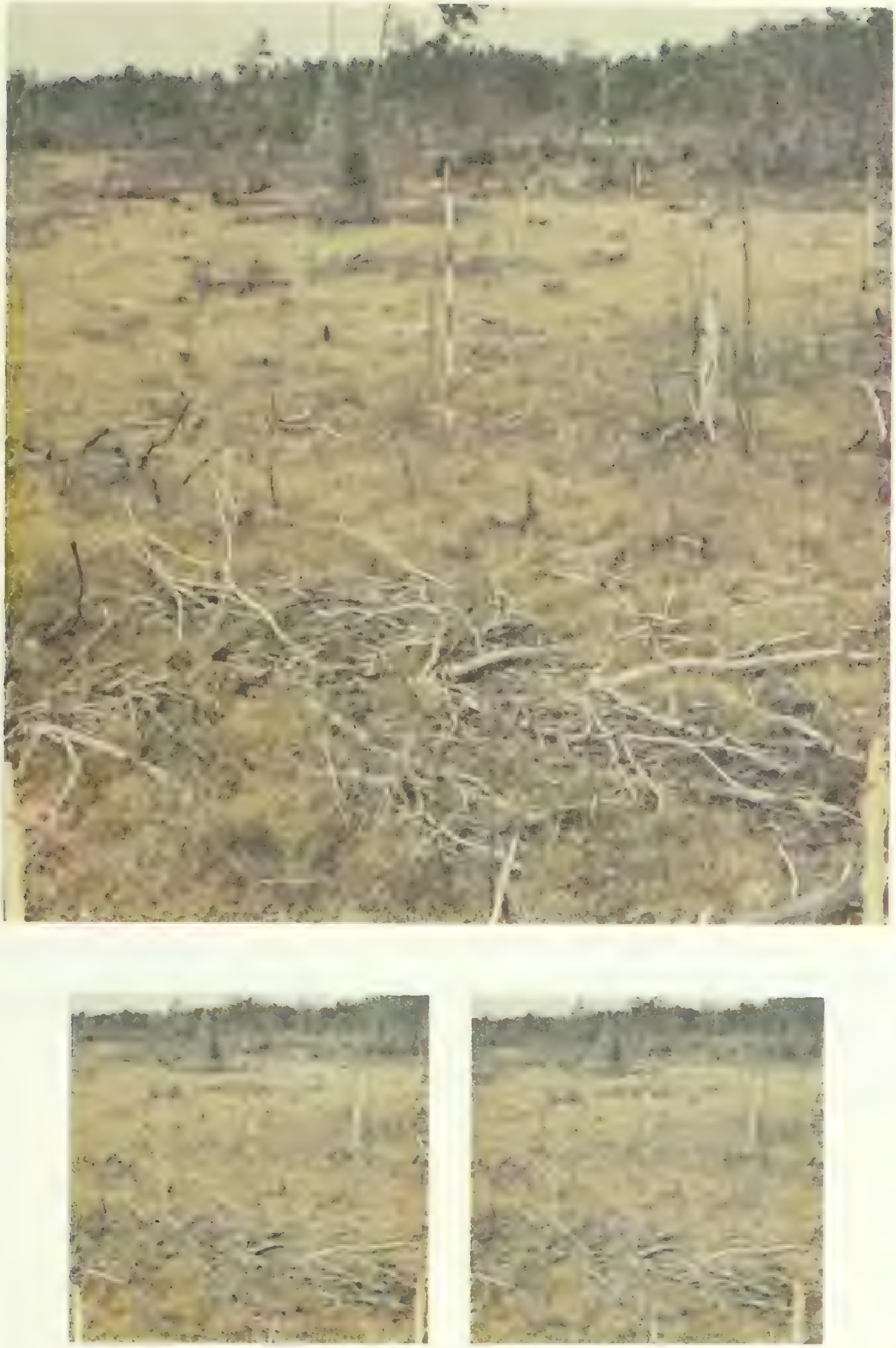

Photo 8.—*Three-year-old slash, 12 tons/acre.*

Data sheet 9.— **Approximate fuel amounts in areas similar to Photo 9.**

Fuels	Tons/acre	Height or depth
		Inches
Slash		
Branches		
0.0 -0.25	1.7	
0.26-1.0	4.6	
1.01-3.0	5.8	
3.0+	4.7	
Needles	0.2	
Subtotal	17.0[1]	
Grasses	0.5	9.0
Forbs	—	—
Shrubs	0.6	7.0
Litter	6.8	0.5
Duff	10.5	0.9
Subtotal	18.4	
Grand Total Fuel Loading	35.4	

[1] Vertical distribution of slash:

Height (feet)	Tons/acre
0-1	15.7
1-2	1.2
2-3	0.1

Location and Date: Sec 8, T24N,R2W, Roscommon Forest area, Michigan Department of Natural Resources; August 1979.

Stand Information: 46-year-old jack pine. Site index was 50; basal area 180 square feet/acre. Most of the larger material is hidden in the grass.

Method of Harvest: Feller-buncher and chain saw.

Time of Harvest: 1976.

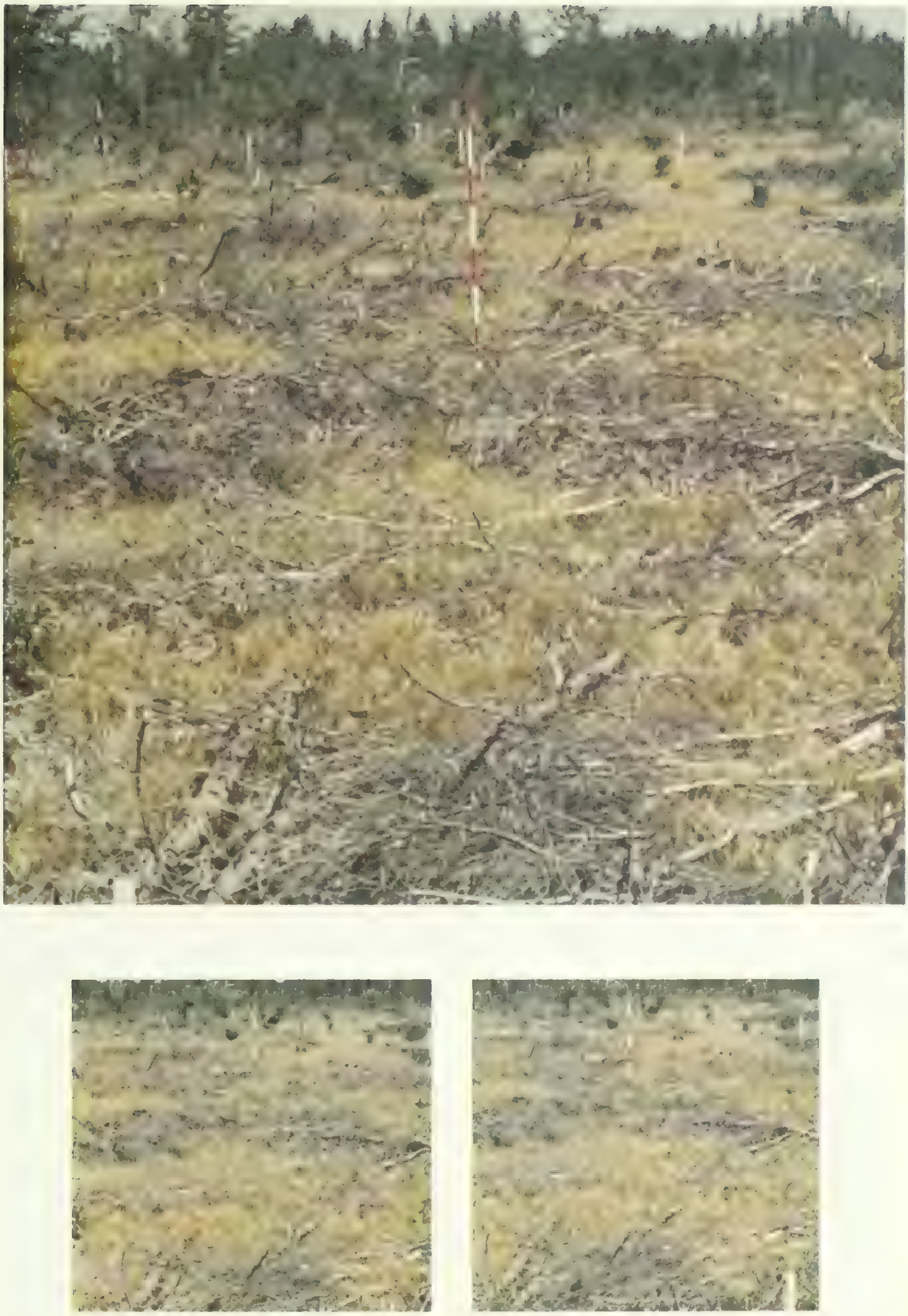

Photo 9.—*Three-year-old slash, 17 tons/acre.*

Data sheet 10.—**Approximate fuel amounts in areas similar to Photo 10.**

Fuels	Tons/acre	Height or depth
		Inches
Slash		
Branches		
0.0 -0.25	0.1	
0.26-1.0	0.3	
1.01-3.0	0.5	
3.0 +	1.7	
Needles	—	
Subtotal	2.6 (Total weight lies within1 foot of ground)	
Grasses	—	—
Forbs	—	—
Shrubs	—	—
Litter Duff	1.7	0.1
Subtotal	1.7	
Grand Total Fuel Loading	4.3	

Location and Date: Same as photo 9, only after burning; October 1979.

Prescribed Burn Information: The prescribed burn was on 9/19/79 after 28 days since the last rain of 0.56 inch. Perimeter ignition was used for lighting the fire at 13:35; ignition was complete at 14:05. At 12:30 the temperature was 58°, wind 6 MPH, relative humidity 38 percent, and cloud cover 0 percent. Using NFDRS Model C, the spread component was 1, energy release component was 16, ignition component was 28, and burning index was 5. All material 2.75 inches in diameter and smaller was consumed in the burn.

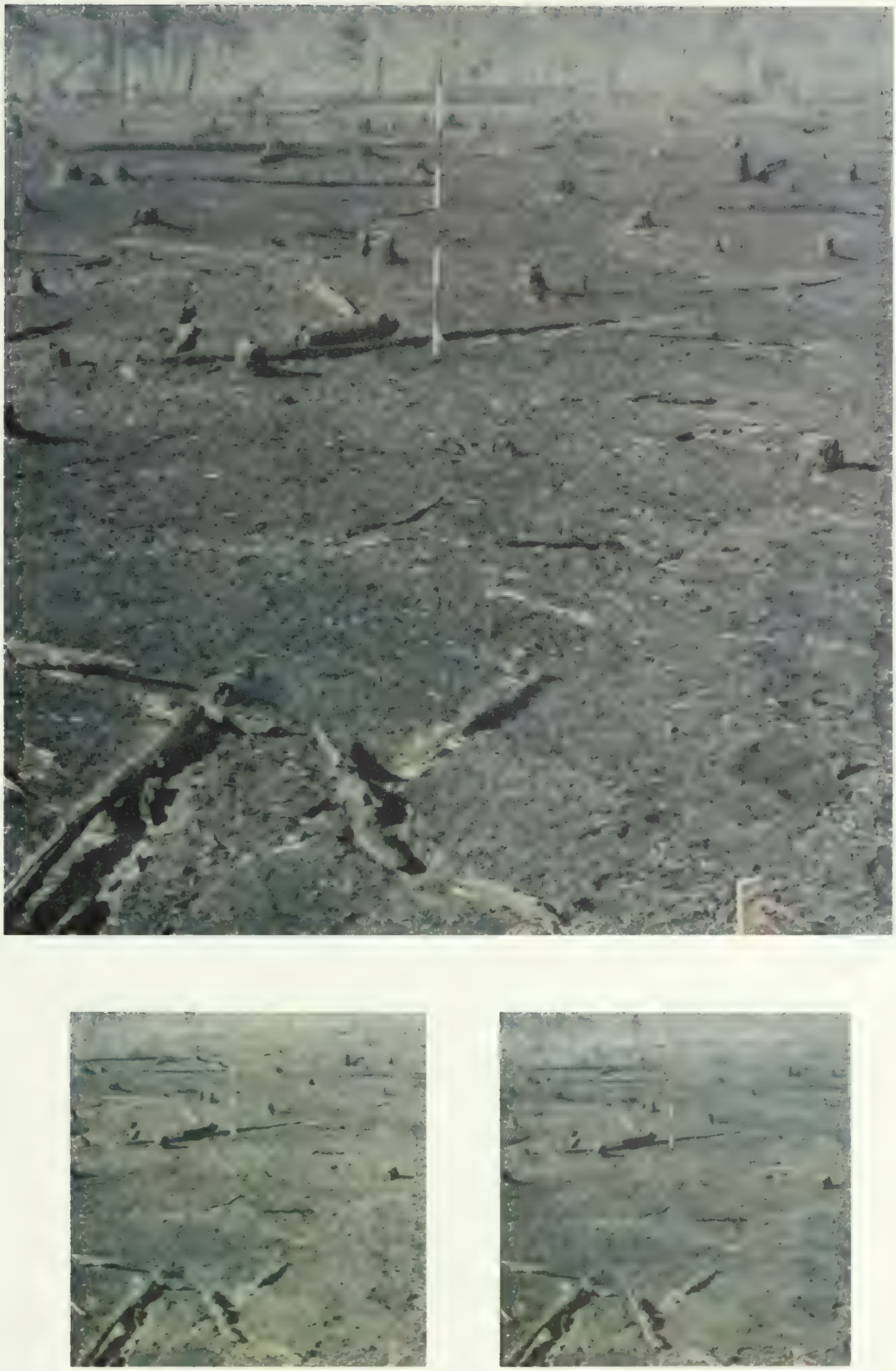

Photo 10.—*Three-year-old slash, 3 tons/acre (post-burn).*

Blank, Richard W.

Stereo photos for evaluating jack pine slash fuels. Gen. Tech. Rep. NC-77. St Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1982. 23 p.

Describes a quick, visual method for estimating jack pine logging residue and other fuels. The method uses a series of large color photographs and stereo pairs as well as data sheets that detail size classes and loadings of the logging slash and other fuels.

KEY WORDS: Residue management, stereo photos, slash loadings, fuel loadings, planar intersect sampling method, prescribed burn.

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Establishing Intensively Cultured Hybrid Poplar Plantations for Fuel and Fiber

Edward Hansen, Lincoln Moore, Daniel Netzer,
Michael Ostry, Howard Phipps, and Jaroslav Zavitkovski

ACKNOWLEDGMENT

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SUMMARY

Intensive culture is the application of agronomic principles and practices for the attainment of forestry objectives. The system is similiar to mechanized farming and is characterized by high energy inputs, high biomass yields, and complete mechanization. Intensive culture includes (a) establishing plantations using thorough site preparation, weed control, and mechanized planting, (b) short rotation, (c) close spacing, (d) fast growing hybrids or genetically improved trees, (e) fertilization, (f) irrigation, and (g) insect and disease management. Some of the factors such as proper site preparation and weed control are essential to successful plantation establishment. Other factors may not be critical by themselves but must be incorporated to attain maximum growth. This paper describes a step-by-step procedure for establishing commercial size intensively cultured plantations of hybrid poplar and summarizes the state-of- knowledge as developed during 10 years of field research at Rhinelander, Wisconsin.

ENGLISH–METRIC CONVERSIONS

Multiply	by	to obtain
inches	25.4	millimeters
feet	0.3048	meters
miles	1.6093	kilometers
pounds/acre	1.1208	kilograms/hectare
tons/acre	2.2417	tonne/hectare
gallons	3.7853	liters

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Establishing Intensively Cultured Hybrid Poplar Plantations for Fuel and Fiber

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Intensive culture of trees has gained much interest the last decade due to projected fiber shortages, competing demands for forest land, and most recently the use of wood for energy. Intensive culture has varied meaning in forestry. Intensive culture as referred to in this report includes (a) establishing plantations using thorough site preparation, weed control and mechanical planting, (b) short rotation, (c) close spacing, (d) fast growing hybrids or genetically improved trees (*Populus* in our case), (e) fertilization and (f) irrigation. Of these, close spacing is not necessarily an essential requirement of intensive culture, and irrigation is not expected to be widely used because of its high cost. The forest management system of intensively cultured hybrid poplar (ICHP) plantations is the application of agronomic principles and practices to attain forestry objectives (fig. 1). The system is similar to mechanized farming and is characterized by high energy inputs, high biomass yields, and complete mechanization. It is designed for application on marginal or unused agricultural land.

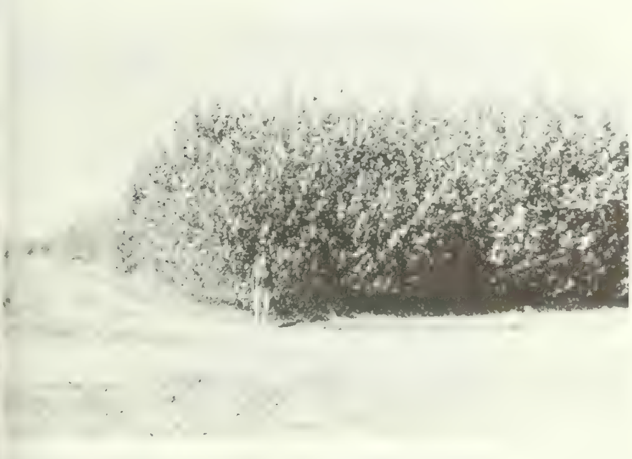

Figure 1.—*Four-year-old intensively cultured hybrid poplar plantations of clone NE-299 (NC-5331) at 6 x 6 ft spacing.*

Knowledge on establishing ICHP plantations is in its infancy. Only in the last few years has knowledge progressed to the point where commercial sized plantations can be successfully established. But even now the success of establishing large plantations is not assured for a variety of sites.

Research at Rhinelander, Wisconsin, on ICHP plantations began in 1970. Research on plantation establishment accelerated greatly in 1977 with initiation of 5 years of funding support from the Department of Energy (at that time the Energy Research and Development Administration). This paper describes a step-by-step procedure for establishing commercial size ICHP plantations and summarizes the state-of-knowledge as developed at Rhinelander. Our intent is to provide useful guidelines for practitioners of intensive culture. As such it updates our previous recommendations (Hansen *et al.* 1979). For purpose of this report we refer to the "plantations establishment period" as that period of time from initial site preparation up through the second year of tree growth at which time the tree canopy closes in close-spaced plantations.

These guidelines are based on the current best practices (although in some instances several similar practices are possible with little difference in effectiveness from one another). Alternatives to the recommended practices, supporting data, and discussion are presented in subsequent sections. It is to be expected that the following guidelines will be modified in the future as more information is acquired.

This plantation establishment system was developed and therefore is adapted to the soil and climatic conditions at the Harshaw Forestry Research Farm near Rhinelander, Wisconsin. The prescribed treatments may have to be adjusted for other sites based on judgement as to how much the site differs from that at Rhinelander. Therefore, we will briefly describe the Rhinelander site to serve as a base or starting point.

Soils: The land was farmed for about 50 years and potatoes were the major crop. It is level to gently rolling with some potholes that contain water for a few days to weeks in early spring or after extraordinary summer rains. Soils are Padus and Stambaugh series grading from a silt loam to a sandy loam. A plow layer at 10 inches separates the topsoil from a sand to gravelly sand subsoil that extends down more than 10 feet. Almost all the *Populus* roots are above the plow layer even though deeper rooting does not appear to be restricted. A few roots of 3- and 4-year-old trees do reach depths of 3 feet and they may be important in extracting the available soil moisture during late summer. Soil moisture is almost always fully recharged in early spring. The soil in the plow layer is high in potassium and phosporus (500 pounds per acre P and 275 pounds per acre K); has a pH range from 5.4 to 6.3; and averages 3.3 percent in organic matter.

Climate: The ground is free of snow for any significant duration from April to mid-November. The growing season for *Populus* is May through September, although there is a 40 percent probability that below freezing temperatures will occur after May 22 and before September 20 (Wisconsin Department of Agriculture 1961). Light frosts frequently occur as late as mid-June and as early as mid-August. Mean monthly temperatures during June, July, and August range from 64 to 68°F; the mean monthly January temperature (the coldest month) is 13°F. Rainfall averages 31 inches per year and monthly averages range from 3.75 to 4.70 inches during the major growing period of June, July, and August.

Vegetation: Both bigtooth aspen, *P. grandidentata,* and quaking aspen, *P. tremuloides,* are native to the area; cottonwood, *P. deltoides,* is not—the northernmost limit of its range in Wisconsin ends about 50 miles south of Rhinelander. The major weed competitor on "old field" sites is quack grass *Agropyron repens.* Other important weeds are yellow rocket *Brassica* spp. (winter annual), pigweed *Amaranthus* spp., lambsquarters *Chenopodium album,* white cockle *Lychnus alba,* and marestail *Conyza canadensis* (perennials). These weeds are different from the con petitors normally found in forest plantations.

PLANTATION ESTABLISHMENT PRESCRIPTION

Populus species used in ICHP culture are fro the Aigeiros or Tacamahaca sections, which are ea ily propagated by stem cuttings. Species from tl Leuce section (aspens) are not used because of tl difficulty of rooting stem cuttings.

Hybrid poplars are propagated by means of ve etative cuttings. The plants thus produced are g netically identical to the parent and are collective called the "clone". The proper clones to plant on particular field depend on the soil and climate ar are best determined by clonal comparison trials dor under similar field conditions.

Site Preparation—Weed Control

Initial site preparation including control of cor peting weeds is essential for successful establisl ment of ICHP plantations. Begin site preparation i the fall prior to spring planting. Add lime as ne essary to raise soil pH above 5.5. Mow grasses ar weeds in August or early September to reduce heav vegetation and allow grasses time to regrow. Appl a postemergent herbicide such as glyphosate (Roun up) at 1.5 pounds active ingredients (ai) per acre i late September or early October to kill weeds ar grasses—especially quack grass. One week later di the sod and then moldboard plow to the 10 inch dept (fig. 2). In the spring, disc the site and just befo planting apply a preemergent herbicide such as li uron or diuron at 1.5 pounds ai per acre to contr germinating annual weed and grass seed (fig. These herbicides control weeds for the first 4 to weeks after planting and allow time for the pla tation to become established.

With initial good weed control using these pra tices, we have found no advantage to tree grow from further weed control during the first growi season in fertilized and irrigated plantations. spacings such as 3.3 x 3.3 feet or narrower, wee are shaded out by the middle to end of the seco year under conditions of good growth, and weed co trol is no longer needed. At wider spacings, part ularly in unirrigated and unfertilized plantatio further weed control will be beneficial.

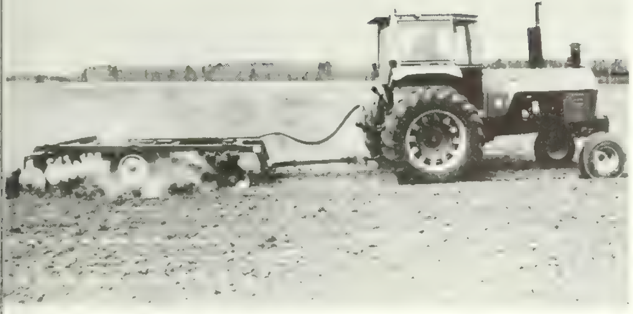

Figure 2.—*Site preparation includes plowing and discing to control early weed competition and to permit mechanized planting.*

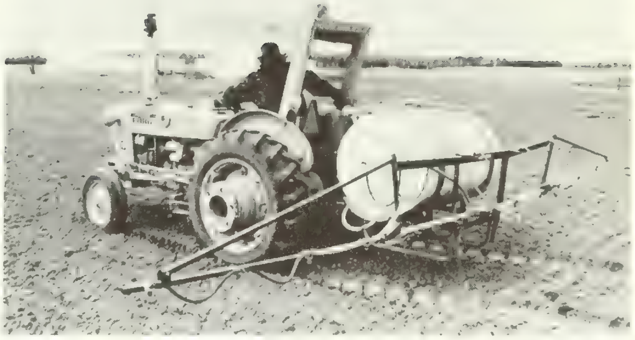

Figure 3.—*Spraying linuron just before planting prevents weed growth for 4 to 6 weeks.*

Clonal Selection

The results of 5 years of clonal tests at Rhinelander can be used as a guideline for clonal selection table 1). In general northeast (NE) clones grow better in northern Wisconsin than do Euramericana DN) clones. However, information is not adequate at this time to recommend particular clones for specific sites with guaranteed success. It is advisable to make local trials to select fast growing clones that root easily, are resistant to insects and disease, and are adapted to the local climate and soils. A group of clones, as compared to a single clone, will reduce the risk of large scale plantation losses.

Clonal trials can consist of a few trees per clone 10 is sufficient) with just one clone per row to avoid mixing clones. It is not necessary to replicate plantings for clonal selection. It is far more beneficial to test additional clones or to test them over the range of planting sites than to improve selection by more precise between-clone comparisons. Clonal selection trials should be maintained for as long as a planting program exists, because these trees are oldest and may show impending problems before they develop in the plantations.

Cutting Production

Planting material most frequently used is dormant unrooted hardwood cuttings obtained from 1-year-old stump sprouts. The production, collection, and handling of cuttings in covered next.

CUTTING ORCHARD MANAGEMENT

Cuttings to establish ICHP plantations are produced in cutting orchards or stool beds. A 3.3 x 3.3 foot spacing seems to be satisfactory from the standpoint of high cutting production and good natural weed control from shading. A cutting orchard with 3.3 x 3.3 foot spacing producing an average of 30 cuttings per stump would provide sufficient cuttings to plant an area 120 times larger using a planting spacing of 6.6 x 6.6 feet. An important factor in the establishment of ICHP plantations is to use vigorous, disease- and insect-free, planting stock. Ideally, cutting orchards should not be established directly adjacent to natural or planted stands of poplars where pests may build up and eventually invade the cutting orchard. Cultural measures for cutting orchards such as site preparation, weed control, fertilization, and irrigation are the same as for production plantations and are discussed in the sections that deal with those topics.

HARVESTING

Trees in the cutting orchard should be allowed to grow for 2 years to develop a strong root system and then harvest the stump sprouts or whips annually. Cut 1-year-old whips 4 to 6 inches above the ground between December and March. We have cut these whips successfully using hand pruning shears, a gasoline powered brush-clearing saw, and a tractor mounted sickle bar, but they can be cut by any method (fig. 4).

Table 1.—*Clonal ranking based on index of volume D^2H (where D is the breast height diameter and H is tre height) of unirrigated and unfertilized 5-year-old trees at Harshaw Forestry Research Farm near Rhinelande Wisconsin. Any two D^2H not next to a common line are significantly different. Ranking for some of the sam clones based on irrigated and fertilized 4-year-old height from plots on a sandy nursery site at Rhinelande are also shown.*

Clone						
Original number	North Central number	Parentage[2]	Height	D^2H	Survival	Nursery[1] ranking
			Feet		*Percent*	
NE-386	5263	*P.* 'Candicans' x (*P.* x *berolinensis*)	23.7	46.1	81	2
NE-387	5262	*P.* 'Candicans' x (*P.* x *berolinensis*)	23.5	34.1	88	3
NE-252	5334	*P. deltoides* var. *angulata* x *P. trichocarpa*	22.6	34.1	75	
NE-372	5266	*P. deltoides* var. *angulara* x *P. trichocarpa*	22.2	28.7	62	8
NE-298	5332	*P. nigra* var. *betulifolia* x *P. trichocarpa*	21.0	27.1	91	4
NE-375	5264	*P. deltoides* var. *angulata* x *P. nigra* var. *plantierensis*	21.0	24.2	78	
NE-1	5272	(*P. nigra* x *P. laurifolia*) 'Strathglass'	21.9	23.4	94	
—	5339	(*P. alba* x *P. grandidenta*) 'Crandon'	18.9	18.7	66	
DN-28	5325	*P.* x *euramericana* 'Ostia'	18.1	16.1	25	
—	5377	*P.* x *euramericana* 'Wisconsin #5'	20.2	15.2	100	6
DN-34	5326	*P.* x *euramericana* 'Eugenei'	18.4	11.1	66	5
DN-30	5323	*P.* x *euramericana* 'Canada Blanc'	17.4	9.9	94	
—	5351	*Populus* spp.	15.9	8.7	94	
—	5260	(*P. tristis* x *P. balsamifera*) 'Tristis #1'	15.3	8.2	88	1
—	5258	*Populus* spp.	16.3	6.8	97	7
—	9922	*Populus* spp.		(3)		
I-476	4879	*P.* x *euramericana*		(3)		
—	9921	*Populus* spp.		(3)		
NE-299	5331	*P. nigra* var. *betulifolia* x *P. trichocarpa*		(3)		
NE-388	11505	*P. maximowiczii* x *P. trichocarpa*		(3)		
P1343437	4877	*P. alba*		(4)		
I-214	4878	*P.* x *euramericana*		(4)		
—	5261	(*P. deltoides* var. *occidentalis* x *P. balsamifera*) 'Northwest'		(4)		
NE-374	5365	*P. deltoides* var. *angulata* x *P. trichocarpa*		(4)		
NE-366	5267	*P. deltoides* x *P. nigra* var. *caudina*		(4)		
NE-216	5268	*P. deltoides* x *P. trichocarpa*		(4)		
NE-19	5271	*P. nigra* var. *charkowiensis* x *P. nigra* var. *caudina*		(4)		
FNS-4452	5273	*P. deltoides* 'Walker'		(4)		
D-37	5318	*P. deltoides* 'D-37'				
D-45	5319	*P. deltoides*		(4)		
JAC-6	5320	*P. deltoides* x *P. balsamifera*		(4)		
DN-31	5321	*P.* x *euramericana* 'Negrito de Granada'		(4)		
I-78-B	5322	*P.* x *euramericana* 'Jacometti'		(4)		
DN-26	5324	*P.* x *euramericana* 'B-56'		(4)		
I-45/51	5328	*P.* x *euramericana* 'I-45/51'		(4)		
NE-348	5335	*P. deltoides* x *P. trichocarpa*		(4)		
—	7168	*P. balsamifera*		(4)		
NE-310	9927	*P. nigra* var. *charkowiensis* x *P. nigra* var. *caudina*		(4)		
NEA-238	9980	*P. deltoides* x *P. nigra* 'Volga'		(4)		

[1] Data from Meldahl, 1979 tables 12-20.

[2] Names according to Dr. Dickman, Department of Forestry, Michigan State University, East Lansing, MI 48824.

[3] Clones not ranked because they were not included in the comparative tests. Based on growth in large plantations and other year-old clonal trials, clone 9922 would probably rank at or near the top clones, I-476, 9921, and NE-299 would rank in the t seven, and NE-388 would not be suitable due to recurrent severe frost damage.

[4] Unsuitable clones due to frost damage and/or disease.

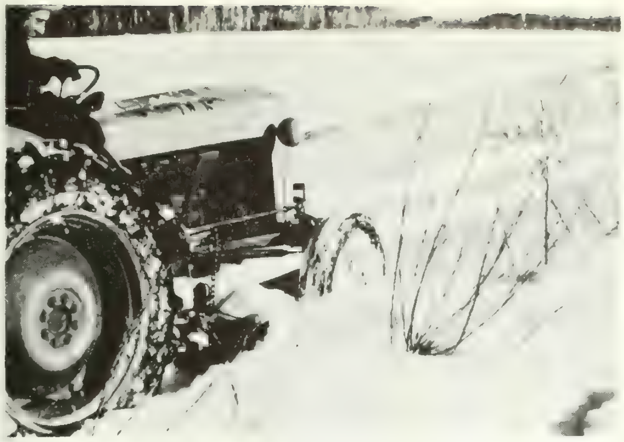

Figure 4.—*Cutting whips with a tractor mounted sickle bar.*

Remove and discard all branches and the lower 2 inches of the whips. Use a table saw, band saw, or radial-arm saw to cut the whip into 8-inch long cuttings up to a minimum diameter of about 0.2 inch. Discard the remaining tip.

GRADING

For best early survival and growth select only those cuttings that meet the following minimum standards:

1. A cutting diameter greater than 3/8 inch. Generally, the larger the diameter, the better the field performance.
2. No evidence of mechanical damage such as stripped bark, split or crushed ends, or broken or missing buds near the top of the cutting.
3. No signs of insect or disease infestation such as galls, lesions, eggs, borers, or fruiting bodies.
4. Green inner bark and no desiccated or shrivelled outer bark.

PACKAGING AND STORAGE

Because large-scale harvesting and processing of dormant hardwood cuttings is best done in the winter, the cuttings must be stored for several months before they can be planted.

Packaging

Store cuttings in polyethylene bags. To facilitate inventory, place approximately the same number of cuttings in each bag—taking care to have buds pointing in the same direction—and tie the bag with a wired label tag for clonal identification. Then place several of these bags in a larger polyethylene bag and seal as before. Double wrapping the cuttings is important to prevent desiccation.

Temperature

Store cuttings at 25° to 30°F to prevent premature sprouting and rooting. However, for periods up to a maximum of about 3 months, newly harvested cuttings can be stored at temperatures as warm as 37°F.

PREPLANT TREATMENT

Treating cuttings before field planting as described below improves survival and early growth, especially if hot, dry weather conditions are expected during the first few weeks after planting. These treatments prepare the cutting so that it is ready to begin root and shoot growth soon after planting. However, these treatments must be done carefully, because if carried too far they may result in reduced vigor or survival.

Raising Storage Temperature

Cuttings that have been stored at below freezing temperatures should be allowed to "warm" slightly at temperatures of about 37°F for 1 to 2 weeks before soaking.

Soaking

Soak dormant hardwood cuttings in tap water as follows:

1. Place the bundles, with buds pointing up, in containers of water maintained at about 60°F. The temperature may be as low as 40°F but this will prolong the soaking period. Do not remove the cuttings from the plastic bags, just puncture the bottom and top of the bag to admit water.
2. Immerse the cuttings to the same depth as they will be planted, i.e., about 3/4 of their length.
3. Do not expose the cuttings to light for extended periods of time to avoid premature bud break.
4. Soak cuttings for 7 to 10 days until small swellings or bumps appear on the bark surface (fig. 5). These are the developing roots. Leaf buds should be dormant or only slightly developed as indicated by a slight greening. This is an ideal stage for planting. Cuttings should not be allowed to develop roots and expand leaves.
5. If cuttings cannot be planted within a day or two after the above stage is reached, return them to cold storage (32°F) and pack the cutting bundles in crushed ice to prevent further root and shoot development. This method will maintain the cuttings in good condition for at least 2 weeks.

TRANSPORTING

As with any planting material it is important to avoid damaging the cuttings from exposure to ex-

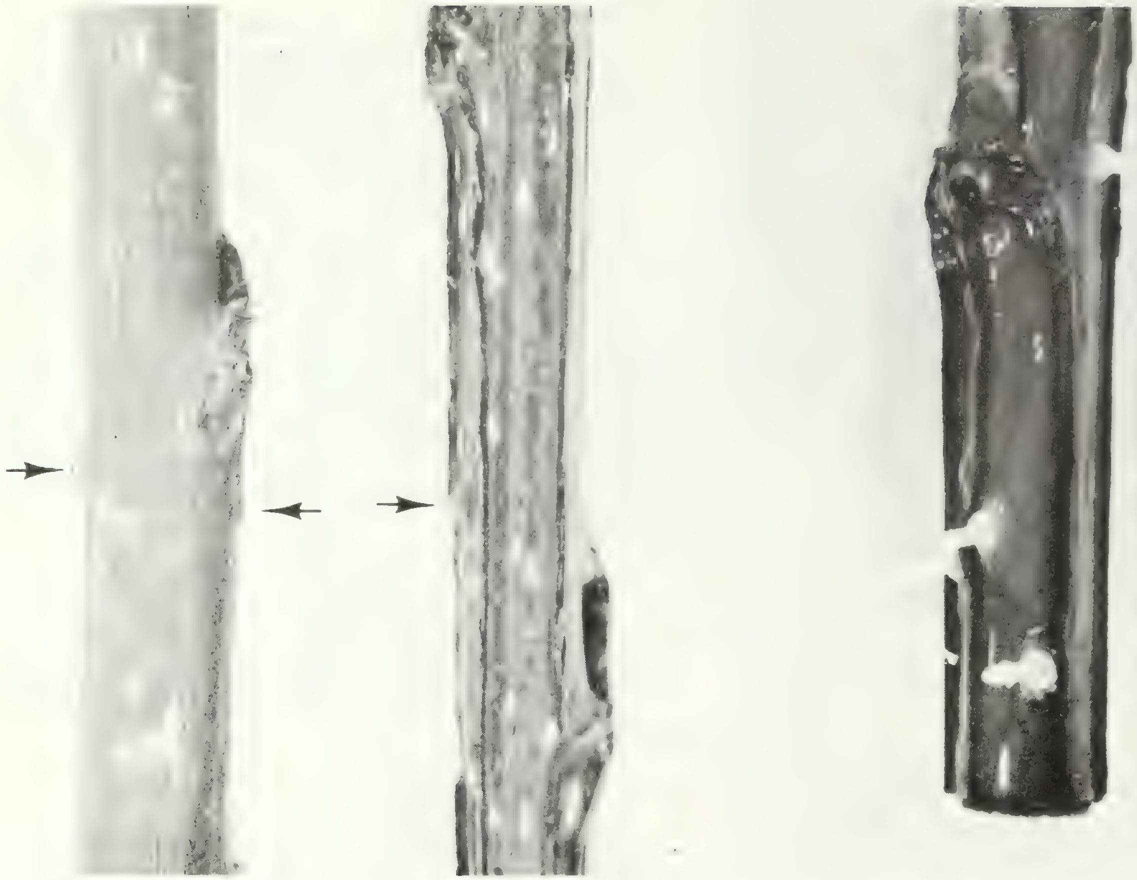

Figure 5.—*Cuttings soaked to (left) proper stage, (right) excessive root development.*

cessive heat or drying. Although soaked cuttings can withstand several hours of drying, it is best to keep them moist, shaded and as cool as possible. Transport the cuttings to the field in the soaking containers, leaving the cuttings in the plastic bag immersed in water. If the cuttings must be in transport overnight or if outside temperatures are high, pack the bundles in crushed ice or in styrofoam coolers.

Planting

At the planting site, exercise the same care in keeping cuttings moist, shaded, and cool.

1. If planting by machine, load the cuttings into a box and then place it on the planting tray of the machine. A semimechanical transplanter model CT-5 is satisfactory for planting on well-tilled sites. The planting units can be "ganged" on a tool bar so that several rows are planted at one time (fig. 6). Each unit can plant about 1,200 cuttings per hour with an experienced operator.
2. Make certain that the cuttings are planted with the buds pointing up. Otherwise, survival and growth will be poor.
3. Plant cuttings vertically to a depth that will leav one to two buds aboveground (fig. 7). For 8-inc cuttings this will require a hole or slit about inches deep.
4. When planting by hand, carry the cuttings in pai with a small amount of water. An efficient to

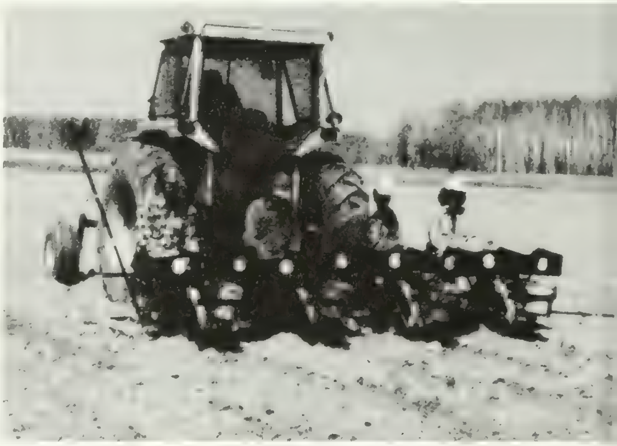

Figure 6.—*A four-row mechanical transplanter c plant unrooted hardwood cuttings at a rate of 5,00 hour at a 3.3 x 3.3 ft spacing.*

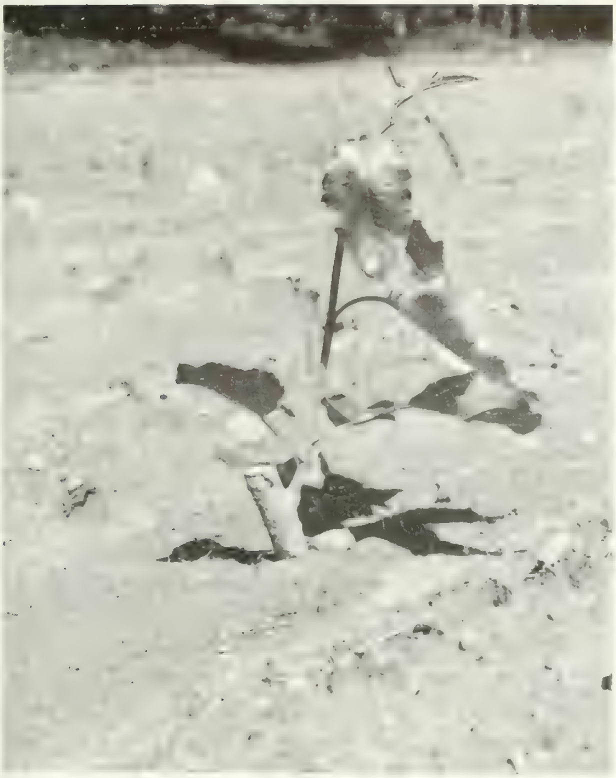

Figure 7.—*One or two buds on the planted cuttings should be above ground. This shoot is 4 weeks old.*

for hand planting cuttings is a dibble made from an iron bar approximately 3/4 inch in diameter with a horizontal projection welded to the bar at a point that will make a hole of the desired depth when the bar is pressed into the ground. Press cuttings into the hole so that firm contact is made between the base of the cutting and soil at the bottom of the hole. Then firm soil around cutting to eliminate air pockets.

5. If the planting operation must be delayed for more than a day, keep the cuttings cool and moist. Pack the cuttings in crushed ice to maintain them in a viable condition and prevent deterioration.
6. Plant unrooted hardwood cuttings anytime from after soil frost has left in early April until mid-June. Cuttings planted in the middle of this period (mid-May) have slightly better survival and height growth than those planted either earlier or later.

Fertilization

Fertilize annually with 100 pounds N per acre per year. This is equivalent to 300 pounds per acre per year ammonium nitrate. Fertilize annually about July 1 if the nitrogen will be applied all at once. Fertilize in small increments from mid-June to early August if the fertilizer can be applied in several applications. If weed control is excellent and the soils have high organic matter content, it may not be necessary to fertilize the first year or two. If weed competition is severe or soils are coarse textured, it is essential to fertilize with nitrogen for at least several years. Phosphorus and potassium fertilization were not required during the first several years at Harshaw Farm because of the high levels of P and K in the soil. However, they may be necessary on other soils.

Figure 8.—*Ideally, soil moisture tension should be maintained at less than -0.5 bar by irrigation. Shown here is a self propelled water gun that delivers 500 gals/min and irrigates a strip 300 feet wide by 1/4-mile long.*

Irrigation

Maintain soil moisture as close to field capacity as possible (-0.05 to -0.2 bar) at the time of planting. Thereafter maintain soil moisture tension at a higher level (less than 0.5 bar as measured at the 6 to 12 inch depth with tensiometers) (fig. 8). If irrigation is not feasible, soil moisture stress can be reduced during the plantation establishment period (until the tree canopies close and completely occupy the site) by providing thorough weed control. Without irrigation, either heavy weed cover or complete canopy closure will usually produce severe soil moisture deficits during the summer.

Spacing-Rotation

The ideal spacing depends upon management objectives such as tree size and fiber markets but is probably somewhere between 3.3 x 3.3 feet and 10 x 10 feet for rotations of 8 to 15 years, respectively. Spacing affects both cost of plantation establishment and the required duration of weed control. Cost of planting material is exponentially related to tree spacing, e.g., plant material costs of a 3.3 x 3.3 foot spacing would be 9 times that of a 10 x 10 foot spacing. Weed control will be necessary for only the first year in dense plantations but may be required for several years in widely spaced plantations.

Stand density can influence prevalence and severity of diseases within a plantation (Schipper 1976). Reduced air movement through dense stands increases duration of leaf wetness resulting from dew, rain, or irrigation; making a more favorable environment for disease development and pathogen spread (McNabb *et al.* 1980).

Selection of spacing commits the manager to a set of practices, many of which cannot be changed in midrotation without adversely affecting the overall economic outcome. Specifically, spacing will affect rotation length, final size of the crop trees, biomass distribution among tree components, nutrient removal, type of harvesting machinery, harvesting costs, and wood recovery from the biomass. Although these are not part of plantation establishment per se, they need to be considered and are therefore discussed in the next section.

A PERSPECTIVE

It is apparent from the foregoing that many variables interact in a complex manner to affect the outcome of plantation establishment. Some factors such as proper site preparation and weed control are essential to successful plantation establishment. Others, such as selecting good quality planting material, clonal resistance to insects and diseases, grading cuttings for size, proper storage, pretreatment preparation of cuttings, planting at the best time, fertilization, etc. by themselves may not be critical determinants of plantation establishment. But it is important to note that the effects of these and other variables are cumulative. Plantations may be established successfully without having all variables at optimum levels. If too many variables are neglected, at best a mediocre plantation will result and at worst the plantation will fail. To attain the present-day maximum growth potential in ICHP plantations, all variables must be incorporated.

It is the managers task to determine the degree to which he should (or can afford to) apply these various practices. In the next section we present some relations and management alternatives and discuss their implications as a possible aid to the many decisions that have to be made.

ALTERNATIVE PRACTICES AND DISCUSSION

Clonal Selection

Studies have shown significant clone x site interactions (Randall and Mohn 1969, Demeritt 1979) indicating that clonal trials may need to be done o different sites. We have found a few important differences in ranking of eight clones grown on tw different sites. Clone NC-5260 ranked much lowe and clone NE-372 (NC-5266) much higher on a unirrigated-unfertilized site with silt loam soil a compared to an irrigated-fertilized nursery site wit sand soil (table 1). The low ranking of NE-372 in th nursery may have resulted from declining vigor because the entire clone died the following year. However, we attribute the difference in ranking of NC 5260 to clone x site interaction. Site and environmental factors can influence host resistance to man diseases and insect pests. Tables 2 and 3 list th clones tested and their relative susceptibility to th most serious diseases and to the cottonwood leaf beetle, *Chrysomela scripta,* in the north central regio and can be used as a guide in selecting clones fo use.

In our clonal trials we have found little information gain from replication. Clonal ranking base on only one replicate is nearly the same as that fro two replicates. Therefore, for forest managers whos objective is to select a group of fast-growing clones information could be increased from the same amoun of land and labor by testing additional clones or testing clones on different sites rather than by replicating.

Clonal trials should last many years because th clonal ranking changes as disease or unusual frost slow the growth of some previously fast growing clone (Schreiner 1972, Hansen, unpublished data). Wilkinson (1974) concluded that evaluations made close to the anticipated rotation provided a better basi for clonal selection. We conclude the same from ou screening trials. Clonal ranking changes from yea to year because some previously high ranked clone succumb to disease with consequent loss in growt and a decrease in ranking position.

Trees are susceptible to diseases and insect throughout their life, however, the importance o various pests changes with tree age. Generally, foliage diseases of poplars are more important in youn plantations where entire crowns of trees may be affected as compared to older trees that have only thei

Table 2.—*Severity of* Septoria *and* Marssonina *by clone and location 1976-1981 (compare with table 1 for clonal rankings at Rhinelander)*

Clone	Location/Disease Severity[1]								
	Rosemount, MN			Rhinelander, WI			Ames, IA		
	SLS	MLS	SC[2]	SLS	MLS	SC	SLS	MLS	SC
NE-386[5]	H	A	H	L	L	A	H	A	L
NE-387[5]	H	A	M	A	L	A	H	L	M
NE-252	H	A	H	L	A	L	H	A	M
NE-372	H	L	H	A	M	A	H	L	M
NE-298	H	H	M	A	M	A	L	H	A
NE-375	H	L	H	A	L	A	H	L	M
NE-1[5]	H	L	H	L	L	A	H	A	H
NC-5339	A	L	A[3]	L	L	A[3]	L	A	A
DN-28	L	M	L	A	H	A	L	L	L
NC-5377	L	M	A	A	H	A	L	M	A
DN-34	L	M	A	L	M	A	L	M	A
DN-30	L	M	A	A	H	A	L	M	A
NC-5351	H	H	M	A	H	A	Not planted		
NC-5260	L	A	L	L	L	A	A	H	A
NC-5258	L	L	A	A	M	A	A	H	A
I-476	A	M	A	A	M	A			
NE-299[5]	H	A	H	A	M	A	L	M	A
P1343437	A	L	A	Planting failure			Planting failure		
I-214	L	L	L	A	L	A	L	L	A
NC-5261	M	L	L[4]	A	L	A[4]	L	L	A[4]
NE-374[5]	H	A	H	Planting failure			Not planted		
NE-366	L	L	L	L	L	A	M	L	L
NE-216	H	A	H	Planting failure			Not planted		
NE-19	L	A	A	A	L	A	L	L	A
44-52	H	L	A	A	H	A	M	H	A
D-37	L	A	A	Planting failure			L	L	A
D-45	M	L	A	Planting failure			M	A	A
DN-31	L	M	A	A	M	A	L	M	A
1-78-B	L	M	A	A	M	A	L	M	A
DN-26	L	H	A	A	H	A	Planting failure		
1-45/51	L	M	A	A	M	A	L	H	A
NE-349	H	M	H	L	L	A	H	L	L
NC-7168	L	A	A	L	A	A	Not planted		
NE-205	H	M	H	A	M	A	M	M	H

[1] H = Heavy (premature defoliation throughout crown, many stem cankers)
M — Medium (premature defoliation in lower and mid crown, few stem cankers, many branch cankers)
L = Light (no defoliation, few branch cankers)
A = Trace or absent.

[2] SLS = *Septoria* leaf spot
MLS = *Marssonina* leaf spot
SC = *Septoria* canker.

[3] Susceptible to *Cytospora* canker.

[4] Susceptible to *Melampsora* leaf rust.

[5] Susceptible to *Septoria* canker in Michigan.

lower crowns affected. Canker diseases are important throughout the rotation, and root rot, stem, and decay fungi will probably be of increasing importance in plantations of older trees and especially in coppiced stands. Defoliators feed on all-size trees, but borers prefer stems and branches of particular sizes. Disease weakened trees are most susceptible to borers. Sucking insects build up on young trees and affect growth mostly in the first 1-3 years after planting.

Site Preparation

Site preparation is done to control weeds and prepare the soil for planting. A replicated study of five site preparation methods selected to cover the spectrum of possible methods showed some significant differences between the methods (Morris, unpublished data). A herbicide treatment combined with summer fallowing resulted in significantly greater tree height growth than did either a summer fallow without herbicide or a no-till (table 4). Fall plowing (both normal plowing depth and extra deep plowing) were intermediate and not significantly different from the other three treatments. The site preparation that we are using and have recommended in this report ranks second of those tested. The summer fallow with herbicides would probably be more effective in most instances, but it is much more expensive and it requires that one whole growing season be sacrificed to site preparation.

We have found thorough tillage to be an important aspect of site preparation. No-till has consistently ranked near the bottom of the site preparation practices tried in a number of our field trials as it has in more extensive tests by Von Althen (1981). Also, cutworms can be serious in a no-till situation. Nevertheless no-till is being used successfully and is advantageous on wet sites with poor trafficability during spring and fall (Mike Morin, personal communication).[1]

Weed Control

Control of competing weeds and grasses is essential for successful establishment of ICHP plantations and can be done chemically, mechanically, or by using cover crops. Each of these approaches used singly or in various combinations has successfully controlled weeds (Project staff, unpublished data). However, they all have drawbacks under certain conditions.

Hybrid poplars are extremely sensitive to damage from many of the herbicides commonly used in forestry and agriculture. Dry weather may render preemergent herbicides ineffective for weed control; ex-

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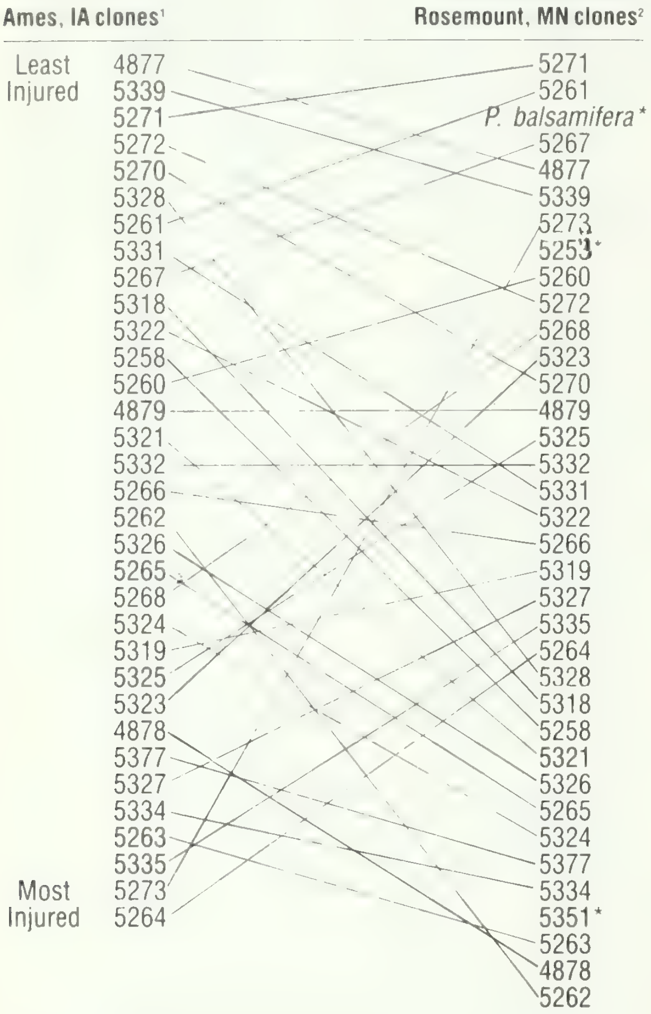
[1] *Consultant, RENRES, Manistee, MI 49660.*

Table 3.—*Comparison and ranking of cottonwood leaf beetle injury between Iowa and Minnesota* Populus *study plots. Iowa data from Caldbeck, McNabb, and Hart (1978). Minnesota data from Wilson (1979).*



	Ames, IA clones[1]	Rosemount, MN clones[2]
Least Injured	4877	5271
	5339	5261
	5271	*P. balsamifera**
	5272	5267
	5270	4877
	5328	5339
	5261	5273
	5331	5253*
	5267	5260
	5318	5272
	5322	5268
	5258	5323
	5260	5270
	4879	4879
	5321	5325
	5332	5332
	5266	5331
	5262	5322
	5326	5266
	5265	5319
	5268	5327
	5324	5335
	5319	5264
	5325	5328
	5323	5318
	4878	5258
	5377	5321
	5327	5326
	5334	5265
	5263	5324
	5335	5377
	5273	5334
Most Injured	5264	5351*
		5263
		4878
		5262

[1] Data recorded as mean percent of leaf area lost from three randomly chosen shoots of three trees per clone.
[2] Data recorded as percentage of two major upper shoots defoliated in 20% categories for all trees.
*Clones only in MN test planting.

Table 4.—*Effect of five site preparation treatments on first year height. Any two heights not next to a common line are not significantly different (p = .05).*

Site preparation	Tree height	Date treatment applied[1]						
		6/23	7/13	7/20	7/20-10/1[2]	10/6	11/6	4/15
	Feet							
Summer fallow w/herbicide	4.1	G	G	D,P	D			D,H
Fall plow	3.8					G	D,P,D	D,H
Fall deep-plow	3.6					G	D,P	LD[3]
Summer fallow	3.3			D,P	D			D,H
No-till	3.3					G	D[4]	

[1] Treatments were: G-glyphosate broadcast spray at 2.2 kg ai/ac, P = plow, D = disc, LD = light disc, and H = harrow.
[2] Disced at about 2-week intervals.
[3] Light disc to smooth soil surface.
[4] Disced to break up sod to permit planting with the mechanical planter.

cessively wet weather may leach the herbicide with consequent damage to trees. Many herbicides have been screened with only a few successful in controlling weeds without damage to the trees (Netzer and Noste 1978). An added difficulty is that *Populus* is not listed on many of the herbicide labels.

Poplars are shallow rooted. Consequently deep cultivation can depress growth or distort root distribution and lead to future windthrow problems. For the first 6 weeks of tree growth we have had good weed control from shallow (2 inch deep) cultivation with a rotary hoe (fig. 9), and for the first growing season we have had good weed control from shallow cultivation with a rolling cultivator (fig. 10). Cultivation is required about every 10 days, which may make it more expensive than chemical weed control, and wet weather sometimes makes cultivation impossible. However, it is usually an effective option if herbicides are not practical.

Cover crops such as clover can successfully prevent weed growth and in addition supply some nitrogen. Clover also appears to limit attack of the tarnished plant bug *Lygus lineolaris* (Sapio *et al.* 1982). However, cover crops (like weeds) compete with the trees for available nutrients and moisture. Fertilization with nitrogen is equally important the first year whether weeds or a nitrogen fixing cover crop is present (Hansen, unpublished data). Cover crops may be more successful in irrigated than non-irrigated plantations because they will compete with trees for moisture where it is limiting.

We have tested many weed control practices and have found no particular advantages between herbicides, cultivation, or cover crops as measured by their effect on first year tree height (table 5). Although a number of significant differences occurred between treatments, much of this variation was due to the weather and the sites. Nevertheless, the following results have been consistent over the years; treatments containing linuron were consistently best; furrow-cultivation was consistently poorest (the shallow planted cuttings desiccated before rooting during the dry spring); and glyphosate applied after the cuttings were planted was poor (due to extreme sensitivity of *Populus*.

Irrigated and fertilized plantations that have good weed control for the first 4 to 8 weeks do not appear to benefit from further weed control during the remainder of the first growing season. In one study with a 3.3 x 3.3 foot spacing, the weeds between rows (primarily quack grass, lambsquarters, and mustard) were shield-sprayed with glyphosate in alternate strips on July 29 during the first growing season. The sprayed strips did not show any superior tree height growth as compared to unsprayed control strips either at the end of the first or the second season (Netzer, unpublished data).

In another study, a number of midsummer weed control treatments were tried in a large plantation with a spacing of 3.3 x 3.3 feet again with little effect on tree height growth (Hansen, unpublished data). Weed control treatments were: 1) weekly hand hoeing from July 6 to August 10 and again on August 26 to keep the plot essentially weed-free, 2) a single application of glyphosate on July 23 with a "ropewick" applicator, 3) a single application of linuron on August 6 by overspraying the trees and weeds, and 4) a control where nothing was done after the initial establishment in the spring. Based on four

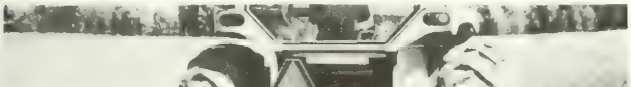


Figure 9.—*A rotary hoe controls weeds both between and within rows but can be used only during the first 6 weeks when the trees are less than 1 foot high.*

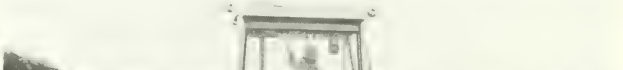


Figure 10.—*A rolling cultivator will control weeds during the first growing season if the field is cultivated about once every 10 days.*

Table 5.—*Effect of eight weed control treatments on first year tree height. Any two tree heights not next to a common line are significantly different (p = .05).*

Weed control treatment	Tree height	Broadcast-spray linuron	Plant cuttings	Cultivate	Shield-spray glyphosate	Seed legume[1]
		Date treatment applied				
	Ft					
Herbicide-legume	3.9	5/6	5/9			8/28
Herbicide-cultivation	3.9	5/6		7/10-8/25(5x)[2]		
Herbicide	3.4	5/6			7/22	
Cultivation	3.3			5/20-8/25(11x)		
Legume	3.2					5/6
Herbicide	2.7				6/11, 7/17	
Furrow cultivation	2.6			6/3-8/25(10x)		
Furrow cultivation legume	2.4			6/3-8/25(10x)		8/28

[1] The legume was white dutch clover.
[2] (5x) signifies 5 cultivations.

replications, only hoeing was slightly (not statistically significant) better than the control. Moreover, hoeing is not a feasible option for large plantations anyway. Both herbicide treatments were poorer than the control (again not significantly so).

Weed control after the first year may also be unnecessary at close spacings but may be beneficial to wider spaced plantations. This was suggested by our tests in 2-year-old plantations of several clones established at spacings from 2 x 2 to 7 x 7 feet. At age 2, the dense undergrowth consisted mostly of quackgrass and its summer biomass reached about 3,700 pounds per acre in the 7 x 7 foot plantings and about one-half of that in the densest 2 x 2 foot planting. Fall and spring spraying of parts of each plantation with glyphosate at 2 pounds ai per acre effectively controlled quackgrass. However, a dense cover of mostly dicotyledonous weeds developed in sprayed areas of the 7 x 7 foot plantings during the third year. In control areas quackgrass still predominated. The total weed biomass of the control areas was about 20 percent greater than that of the sprayed areas but the difference was nonsignificant.

Effects of weed control from spraying glyphosate at the end of the second year showed no significant gain in the third through fifth year current annual woody biomass increment for most clone-spacing combinations (table 6). However, the *Populus* x *euramericana* (NC-5377 and DN-34) clones produced significantly greater biomass on the wider spaced (6.9 x 6.6 foot) sprayed plots.

Table 6.—*Effect of weed control from fall or spring application of glyphosate at age 2 on current annual biomass increment of hybrid poplar at ages 3, 4, and 5. Control plots had no weed control.*
(In t/ac/yr)

Clone	Spacing	3 Control	3 Fall	3 Spring	4 Control	4 Fall	4 Spring	5 Control	5 Fall	5 Spring
		Age (years)								
	Feet									
NE-299	2.3x2.3	5.9	6.2	4.9	7.3	6.7	6.6	5.0	4.7	4.8
	3.6x3.6	4.4	5.0	4.9	7.1	6.1	6.8	——lost——		
	6.9x6.6	2.7	2.7	4.1	6.8	6.2	6.6	6.4	6.6	lost
NC-5260	3.6x3.6	2.7	2.6	4.1	6.2	6.2	6.2	3.6	3.8	4.2
	6.9x6.6	0.6	1.0	1.3	3.3	5.9	6.8	5.3	5.6	6.1
NC-5337	3.6x3.6	3.7	2.4	2.5	4.7	3.5	3.8	2.7	2.8	3.1
	6.9x6.6	0.5	0.7	0.6	1.5	2.2	2.4	1.6	2.3	3.0
DN-34	6.9x6.6	0.2	0.5	0.7	0.8	1.8	2.2	1.1	2.1	2.5
Overall Mean		2.6	2.6	2.9	4.7	4.9	5.2	3.7	3.8	4.0
	S.D.	2.1	2.0	1.8	2.6	2.0	2.1	2.0	1.6	1.3

We conclude that little can be done with further weed control to improve upon tree growth in 3.3 x 3.3 foot or closer spaced irrigated and fertilized plantations if they have been established with initially good weed control. However, further weed control may be beneficial for wider spacings and, we believe, it is highly beneficial for non-irrigated and nonfertilized plantations.

Insects and Disease

Diseases and insect pests that may be of minor importance in natural poplar stands can cause plantation failure or reductions in quantity and quality of fiber yields of ICHP plantations. Large, densely planted, monoclonal stands of even-aged trees exotic to a region are vulnerable to attack by insects, mites, fungi, viruses, and bacteria throughout all stages of an intensive culture program. Pest management considerations made prior to or during nursery or plantation establishment and integrated with other management activities can help avoid or minimize future problems.

To determine what diseases and insects were potentially damaging to hybrid poplars in the north central region of the United States and what clones exhibited resistance to them, a series of small plots, each containing 36 clones of poplar species and hybrids, were established in 1976 and 1977 (Ostry 1979). Since these plantings were established, several potentially serious diseases and insects have developed in them and many additional pests of possible periodic importance have also been detected. Foliage diseases caused by *Melampsora medusae, Marssonna brunnea,* and *Septoria musiva* result in premature defoliation that reduces growth (figs. 11, 12) (Schipper *et al.* 1978, Palmer *et al.* 1980b, and Palmer *et al.* 1980a). Trees that are repeatedly infected become stressed and weakened and are then subject to attack by stem diseases caused by *Cytospora, Dothichiza,* and *Phomopsis. Septoria,* in addition to causing a leaf disease, also causes a serious branch and stem canker that can jeopardize the success of a plantation (fig. 13). These weakened trees attract insect pests.

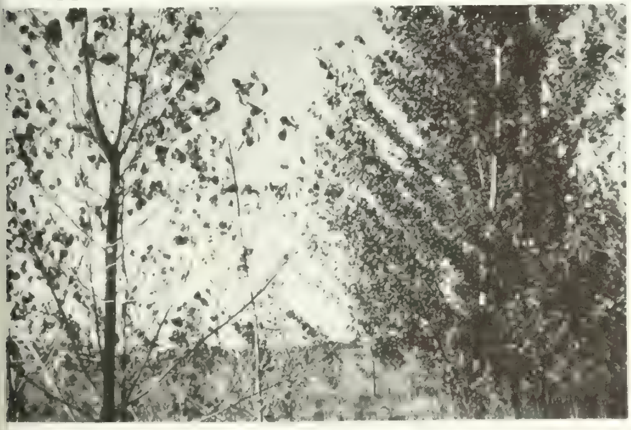


Figure 11.—*Premature defoliation of susceptible trees (left) caused by* Septoria musiva *contrasted to resistant tree.*

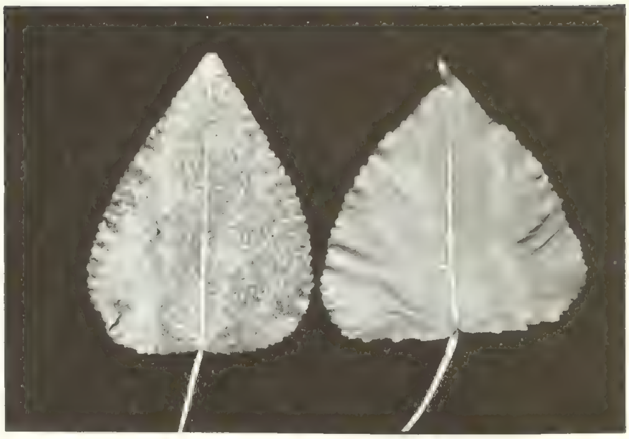


Figure 12.—*Infected and healthy leaves of trees in fig. 11.*

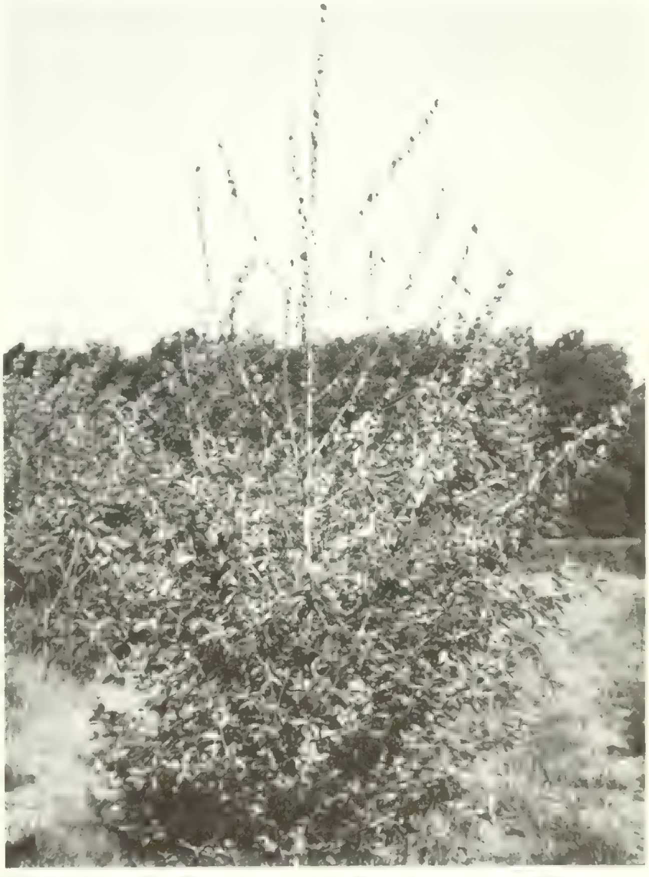


Figure 13.—*Dieback of tree infected with* Septoria *canker.*

Three major conclusions can be drawn from results of the screening plots:

1. Different poplar diseases and insects may be of more importance in one area than another. For example, *Melampsora* rust is far more severe in Rhinelander, where larch, its alternate host, is present, than in Iowa where rust spores arrive later in the season and trees therefore are not infected until late in the season (Widin and Schipper 1981). This illustrates the importance of locally screening clones for disease and insect resistance before they are widely planted.
2. Disease organisms often take several years before they become a serious problem. For instance, *Marssonina* was not prevalent in plantings at Rosemount, Minnesota in 1975. However, since then it has become epidemic on susceptible clones. *Septoria* leaf spot was low and *Septoria* canker absent on trees at Rhinelander until 1981. It is expected that this disease will increase in importance there, as it has elsewhere in the Lake States. Also, the poplar- and willow-borer, *Cryptorhynchus lapathi*, only recently has become important in Wisconsin and Michigan. Clones NE-252, NE-372, NE-375, NE-374, DN-30, DN-34, and NC-5377 so far have been identified as susceptible to this weevil. It is certain more clones will become affected as more plantations are set out and trees get older.
3. Some pests, although usually of little significance, can under the right environmental conditions, be of periodic importance (Ostry 1980a, 1980b). Consideration must be given to these when various cultural practices are carried out to ensure that conditions are not changed to favor pest development. For instance, weed control appears to favor buildup of the tarnished plant bug. Certain cultural practices including cover cropping with white dutch clover reduce the insect (Sapio *et al.* 1982). Clones most suceptible so far are NE-298, NE-386, NE-387, and NC-9921. Similarly, environmental stresses such as drought and winter injury can predispose trees to pests not ordinarily a problem.

Deer Browsing

A concern in establishing ICHP plantations is deer browsing of newly planted trees. A 7-acre plantation established in an area with a large deer population was sampled for deer damage during the first 2 years. During the first winter deer browsed 55 percent of the 200 trees in the sample plot, removing an average of 4 inches from the terminals of the browsed trees. Trees of all heights were browsed although browsing was less frequent on trees more than 5.5 feet tall. During the second growing season browsed trees grew as much in height as the unbrowsed trees. By the end of the second growing season tree height averaged 10.5 feet, which is above the browsing height of deer, and browsed trees appeared to be of equal vigor and form to unbrowsed trees. Although in this case 4 inches of tree height was lost because of deer browsing, it does not appear that browsing will be a barrier to successful establishment of well-managed irrigated plantations. On less intensively managed and slower growing plantations, browsing in successive years may cause problems with tree growth and form but such data are not available at this time.

Planting Material

Although we recommend and use dormant hardwood cuttings, other types of planting material exist. One-year-old rooted stock is frequently sold by commercial nurseries and in one case has been used for large field plantings by a private corporation (Mike Morin, personal communications). Hardwood cuttings may also be rooted and planted as containerized stock. The advantages of containerized stock are (1) even very small diameter cuttings survive and grow well, (2) the planting season may be extended, and (3) survival may be improved on harsh sites. *Populus* can also be propagated by rooting greenwood tip cuttings in various containers and media or in a dilute nutrient solution (Phipps *et al.* 1977, 1980). Rooted greenwood cuttings can be produced in a short time and may provide additional planting stock if hardwood cutting supplies are inadequate. Also, certain clones or hybrids of *Populus alba* are more easily rooted from greenwood cuttings.

Cutting Production

CLONAL ORCHARD MANAGEMENT

Trees for cutting production have commonly been planted at spacings from 1 to 4 feet within rows and from 10 to 12 feet between rows. Stool beds established in this manner have the advantage of easy access to individual rows and make mix ups between clones less likely than in closer spaced orchards. Sanitation practices are necessary to reduce inoculum from infected stock and are more easily, and thoroughly accomplished in wider-spaced stool beds. Cultural practices such as roguing, and disposal of infected residues together with soil cultivation to bury infected fallen leaf debris can reduce disease severity. Disadvantages are that a larger area is required to produce cuttings compared to block plantings at closer spacings such as 3.3 x 3.3 feet. Also the wide spacing requires continual weed control. Close spacing increases incidence of disease such as *Septoria* canker.

HARVESTING

Harvesting Methods

Harvesting methods vary depending on the number of cuttings to be harvested and the availability of labor. Hand pruners and power brush saws are often used in harvesting operations. Tractor mounted sickle bars can be used to "mow" whips especially if whips from a single stump are tied together prior to harvest. Mechanical harvesting systems are being developed that will cut whips, tie them in bundles and load them on to wagons for transport to the processing area (fig. 14).

Time of Harvesting

When to harvest dormant hardwood cuttings depends on their stage of physiological readiness to develop roots and shoots (vigor) and a convenient harvesting time. Like most deciduous broadleaved species of the temperate zone, *Populus* hybrids require a period of exposure to subfreezing temperatures to reach the proper condition for normal root and shoot development. Date when proper condition is reached depends on climate.

In a greenhouse study on root and shoot development of cuttings taken monthly from November through March, we found development proceeded more rapidly as cuttings were collected later in the dormant period (Phipps and Netzer 1981). Beyond December, however, effects were less pronounced. In a second study, cuttings of several clones were collected monthly from September to December and stored at several temperatures ranging from 4°F to 36°F and then planted in the field. Early results indicate that overall survival and height growth were best for cuttings collected in December (Phipps and Fege, unpublished data). However, cuttings collected in October and November performed almost as well except for those stored at the lowest temperature–suggesting that the tissue of these cuttings was not yet sufficiently hardened to tolerate such a low storage temperature. Cuttings collected in September did not survive or grow well and this early date should not be considered for harvesting.

For many nurseries December or January would also be a convenient time of year to harvest and process cuttings. The main disadvantage, however, in many northern areas is the deep snow and extreme cold in which this operation must be performed. February and March may be alternative collection dates, if this activity does not conflict with other operations. However, soil conditions would have to permit the use of harvesting machinery and the cutting collection would have to be completed before trees break dormancy. Although the results of the studies mentioned above are tentative, it appears that cuttings collected from November through March will perform satisfactorily. Interestingly, the best time to harvest *Populus* cuttings coincides with the best harvesting time to achieve the most vigorous coppice regeneration (stump sprouts) for the next seasons production.

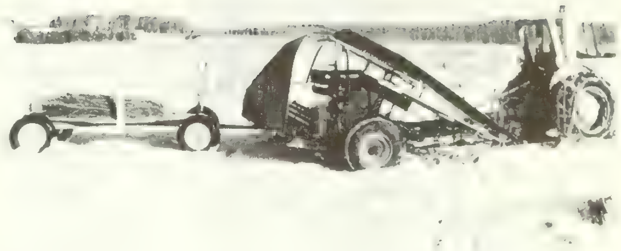


Figure 14.—*A modified corn binder shows promise for mechanically cutting and bundling whips.*

GRADING

One of the most important criteria for selecting cuttings that will survive and grow well after field planting is diameter, measured usually at the base of the cutting. It has been found for some species at least, that hardwood cuttings taken from basal portions of stem shoots root better than those taken near the tip (Hartmann and Kester 1975). This was confirmed for *Populus alba* (Hansen and Tolsted 1981). For most *Populus* clones cuttings with a diameter range from 3/8 to 1 inch will perform well in the field. Cuttings larger than 1 inch may be used if they can be accommodated by the planting machine or will be hand planted.

The effect of cutting diameter on early survival and growth were studied at Rhinelander, Wisconsin, and East Lansing, Michigan (Dickmann *et al.* 1980). One-year-old shoots of six different clones were made into cuttings ranging in diameter from less than 1/4 inch to about 3/4 inch and field planted. Results after one growing season showed that survival and growth increased significantly with diameter (fig. 15). Shoots of small cuttings were only 1/3 to 2/3 as tall as those from large cuttings during the first 11 weeks after planting (fig. 16). During this period,

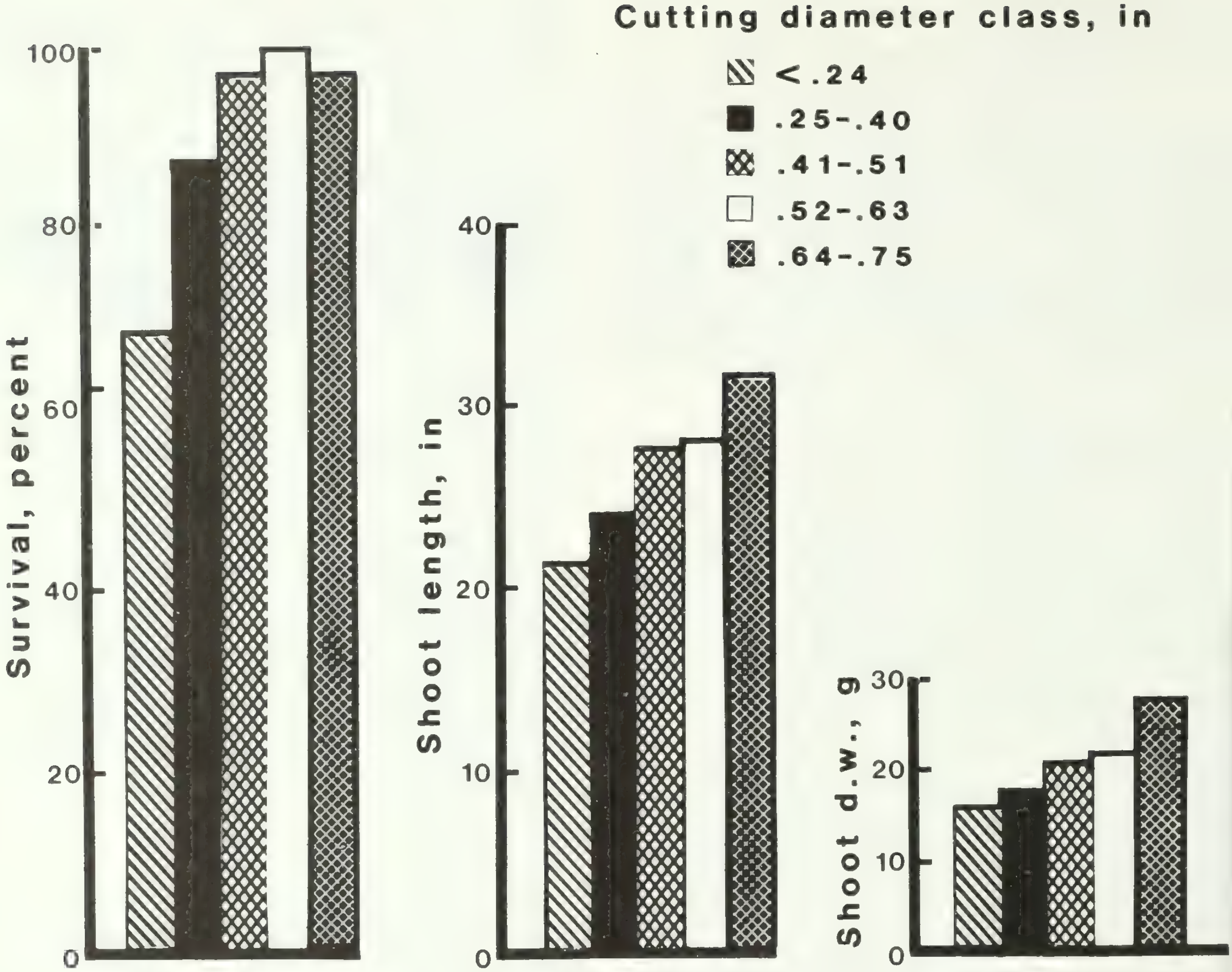


Figure 15.—*Effect of cutting diameter on survival, shoot length, and shoot dry weight (d.w.) of* Populus *cv.* rasumowskyana *x* P. *cv. 'incrassata' (NE-58).*

cuttings are susceptible to environmental stress and weed competition and may fail without irrigation and weed control. The performance of cuttings less than 1/4 inch diameter was very poor and would not be satisfactory for unirrigated field planting. However, small diameter cuttings can be used for clonal stock in nurseries where cultural conditions may be more favorable.

It is imperative to avoid introducing serious pest problems to new areas by carefully examining and culling all diseased nursery stock found. *Marssonina* and *Septoria* and insect eggs and borers can be present on or in hardwood cuttings and spread through an entire plantation if infected or infested stock is planted. A European bacterial canker caused by *Xanthomonas populi,* is not known to be present in our region. Poplar mosaic virus is widely distributed in Europe and has been found in Canada but has no yet been confirmed in the United States (Navrati 1977).

STORAGE

Our experience has shown that dormant har wood cuttings of most clones can be stored at 37° for a maximum of about 3 months. However, at th temperature maintenance of internal bark moistu is critical to avoid losses caused by fungi that attac cuttings in storage. Temperatures at or below free ing are preferable for most storage, and are essenti for long term storage. Cuttings of several differe clones have been successfully stored for 2 years i chest freezers at temperatures between 10 and 20° To prevent desiccation cutting bundles are doub bagged in heavy polyethylene. In areas where wi

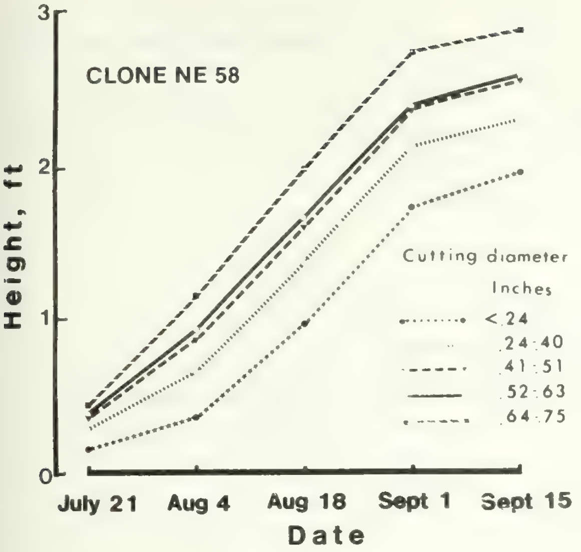


Figure 16.—*Effect of cutting diameter on height growth of clone NE-58 during the first 11 weeks after planting in East Lansing, Michigan.*

ters are sufficiently cold, cuttings may be stored for several months in unheated shelters or buildings without refrigeration. However, late winter temperatures can fluctuate widely and cause the cuttings to break dormancy before they can be planted. Therefore some provision for refrigeration is recommended.

Cuttings stored improperly may be affected by a condition known as blackstem. Microorganisms present on bark surfaces of cuttings cause deterioration of cuttings, killing them directly in storage or weakening them. Weakened cuttings produce unthrifty plants that may be predisposed to other stresses resulting in planting failures.

An alternative to bagging cuttings in polyethylene is to pack them in a moist medium such as sphagnum peat moss in boxes or crates. Early results of a field planting test with cuttings stored by the latter method indicate satisfactory performance. However, special care should be taken that the medium does not dry out. It is also possible that entire stems or whips can be stored without protective covering for a short time before making them into cuttings. In this case, it is essential to maintain humidity in the storage area high enough to prevent desiccation. It is not known if this method could be used for longer periods of storage or at subfreezing temperatures. Further study of storage of entire whips would be necessary before the method could be recommended.

PREPLANT TREATMENT

Raising Storage Temperature

Shoots and roots grow slower on cuttings stored at subfreezing temperatures than on cuttings stored at above freezing temperatures (Phipps and Netzer 1981). In some cases, cuttings stored at subfreezing temperatures fail to develop and eventually die. To compensate for the detrimental effects of subfreezing storage raise the storage temperature to 37°-40°F for 1 to 2 weeks before planting (Phipps, unpublished data). Best results are obtained when this treatment is followed by soaking for from 7 to 10 days at 60°F.

Soaking

Soaking hardwood cuttings in water before planting has been practiced in some parts of Europe and to some extent in the southern United States with cottonwood (*P. deltoides*). McKnight (1970) recommended that cottonwood cuttings be soaked in water until fully saturated (up to 3 days) before field planting. Petersen and Phipps (1976) found that soaking stimulated root emergence and improved field establishment as compared with unsoaked cuttings for three different hybrid *Populus* clones tested.

Field studies have shown a consistent 10 percent increase in height growth due to soaking under conditions of adequate soil moisture (Hansen, unpublished data). Observations of field plantings suggest that the benefit of soaking increases as soil moisture stress increases.

Both water temperature and soaking duration affect subsequent performance of the cutting. Cuttings of two clones were soaked in water at 40°F and 60°F for 2, 4, 6, and 8 days. Cuttings were then grown in a growth room and evaluated in terms of shoot length, number of shoots, and average length of the longest root. Cuttings soaked at 60°F were significantly better then those soaked at 40°F (Phipps, unpublished data). Also, shoots and roots grew longer with increased soaking time, although differences were not significant.

Two questions may frequently confront a field manager:

1. Can cuttings soaked to the proper stage for planting be held in a vigorous condition if planting must be delayed?
2. Will soaked cuttings be severely damaged by short periods of drying that inevitably occur during the planting operation?

In a separate part of the study cuttings were soaked for various lengths of time and then exposed to different combinations of cooling by packing in crushed ice for 2 weeks and/or air drying for 8 hours before planting.

Results indicated that cuttings could be maintained for 2 weeks by packing in ice and returning to cold storage, and cuttings could be subjected to air drying for 8 hours without suffering serious growth loss. However, it should be stressed that best results will be obtained when cuttings are planted as quickly as possible after soaking, and packing in ice must be regarded only as an emergency measure.

Planting

MACHINERY

The semi-mechanical transplanter model CT-5[2,3] is the most efficient planter we have tested for unrooted hardwood cuttings on well-tilled sites. With a 4-row planter our 6-man field crew planted about 5,000 cuttings per hour or in excess of 30,000 cuttings in 6 hours at a 3.3 x 3.3 foot spacing. A 2 unit Model 1525 transplanter is advantageous for stony sites or untilled areas. About 500 cuttings per unit per hour can be planted with this transplanter. This planter also allows planting of rooted stock, containerized stock, or long whips. The Model 1525 planter was slightly modified by engineers at the Forestry Sciences Laboratory in Houghton, Michigan. They added an audible system to control within-row spacing, redesigned the packing system, added larger and stronger planting shoes, and added protective shields for the operators.

DEPTH

Various recommendations have appeared in the literature for best depth of planting hardwood cuttings of different species. Generally, these range from leaving from 2 to 3 buds exposed above ground to planting the cutting flush with the ground level. In most situations leaving 1 or 2 buds above ground or leaving the cutting 1 inch above ground if no buds are present will produce good results with *Populus* hybrid cuttings. Early results of tests designed to determine the effects of cutting length and planting depth showed that 8 inch cuttings produced the least number of main shoots when planted flush with the ground surface in a silt loam soil. However, first-year shoot height was less than that of cuttings planted at shallower depths of either 4 or 6 inches (Phipps, unpublished data). Whether the results would be the same on coarser textured soils remains to be studied.

TIME

It is generally believed that the best time to plant is shortly after soil frost leaves in the spring. However, 3 years of planting throughout the soil frost-free period showed that cuttings planted in April grew less in height during the growing season than those planted in May (fig. 17) (Hansen, unpublished data). In fact, in northern Wisconsin early June planting dates are generally as good as those in April. Mid-May was consistently the best planting time although the increase in growth was slight. August plantings failed each year due to frost heaving of the weakly rooted cuttings. Fall planting resulted in mixed success from year-to-year due to frost heaving; one year out of three resulted in successful establishment. We speculate that fall planting would be more successful on sandy soils or during winters with deeper snowpacks—our two fall planting failures preceded winters with light snowpacks.

Fertilization

Hybrid poplars require large amounts of nitrogen (Hansen and Baker 1979). On our silt loam soils if all weeds were kept out of the plantation by hand weeding, growth was not accelerated from fertilization with 100 pounds nitrogen per acre per year during the first 2 years. In contrast, if weeds are present (as is the case in all field plantations), fertilization significantly increases tree growth (table 7) (Hansen, unpublished data). In our studies fertilization with 100 pounds nitrogen per acre per year increased 1- and 2-year tree height as much as 80 percent on weedy plots. In cases where severe weed competition

Table 7.—*Effect of N fertilizer (applied as* NH_4NO_3*) on 1- and 2-year tree heights on "weedy" and "weed-free" plots*

(In feet)

Fertilizer rate (lbs/ac/yr)	Total seasonal height growth			
	Weedy plot		Weed-free plot	
	1-year-old	2-year-old	1-year-old	2-year-old
0	3.3	4.0	3.7	9.0
50	3.5	4.7	—	—
100	4.7	7.7	—	—
150	4.9	7.2	3.6	8.7

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[2] *Available from Mechanical Transplanter Company, South Central Avenue at US-31, Holland, Michigan 49423.*

[3] *Mention of trade names does not constitute endorsement of the product by the USDA Forest Service.*

develops shortly after planting, fertilization is essential for successful establishment. Fertilizer increases the incidence and attacks by sucking insects but tends to decrease wood borers and some defoliators (Wilson 1976).

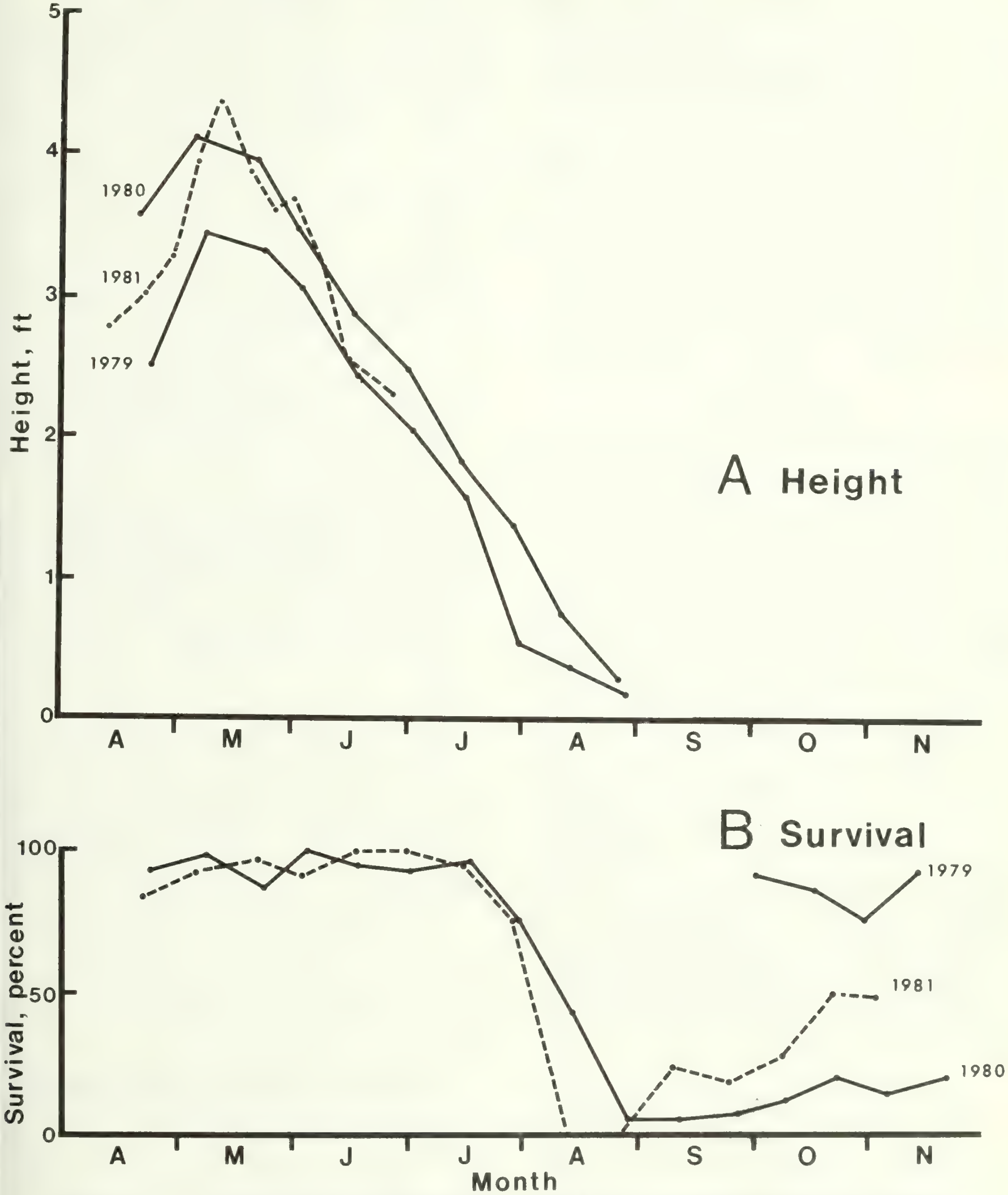

Figure 17.—*(A) Total height and (B) survival of 1- and 2-year-old trees respectively as related to planting date for 3 years of trials with clone NC-9922.*

Seeding an herbaceous legume cover crop such as birdsfoot trefoil in a plantation at or shortly after the time of planting cuttings has the potential for eventually providing nitrogen. However, our studies show no benefit to first or second year tree growth (Hansen, unpublished data). Nitrogen fertilization is required as much the first 2 years with legumes as it is with weeds.

Another future possibility for managing nitrogen on the site is to mix nitrogen-fixing trees such as *Alnus* with the *Populus* (DeBell and Radwan 1979, Hansen and Dawson 1982). However, this concept is still in the developmental stage and not yet ready for commercial plantations.

Soil pH can vary considerably but should be maintained between 5.0 and 7.5 by liming (van den Burg and Schoenfeld 1978, Wolkowski and Schulte 1980).

Irrigation

At the time of planting, soil moisture tension should be −0.2 bar or less. A growthroom study using boxes of soil at different moisture tension levels showed that early shoot growth of unrooted hardwood cuttings increased as soil moisture tensions decreased to at least −0.05 bar indicating that new plantations should be kept moist (fig. 18) (Hansen and Phipps, unpublished data). The time required for bud break and shoot growth to begin also decreased as the soil became wetter. However, in some soils the reduced aeration from rain or irrigation may negate the potential benefits of low soil moisture tension.

Soil moisture can usually be maintained at high levels in early spring by good site preparation and weed control practices that prevent soil moisture withdrawal by weeds. If soils do dry out, moisture levels can be restored by irrigation. If irrigation is not possible and if the planting workload is small, planting can be delayed until after a rain. Also the effects of dry soil can be offset to a large extent by soaking the cuttings prior to planting (fig. 18). (Refer to "Preplant Treatment" section for discussion of soaking technique.) The best planting procedure is a combination of both practices—plant soaked cuttings in a moist soil.

Maintaining high soil moisture is important even after the cuttings begin to grow. In our tests tree volume was greatest at the wettest soil moisture level and was almost double that of unirrigated trees (fig. 19) (Hansen, unpublished data). These results were obtained during the first 2 years of tree growth in a study in which a particular treatment was irrigated whenever the specified soil moisture level was reached. From these results we concluded that the management objective should be to maintain high soil moisture levels by irrigation—if possible. In the absence of irrigation, periods of high soil moisture can be extended by good weed control. But eventually the tree canopies close and the trees completely

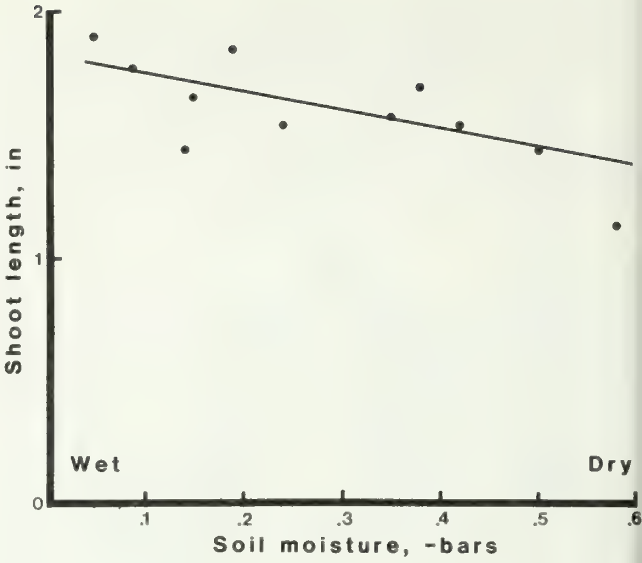

Figure 18.—*Relation of 10-day shoot elongation of clone NC-5260 to the initial soil moisture tension. The cuttings were soaked 10 days prior to planting. Cuttings that were not soaked had not yet begun to grow.*

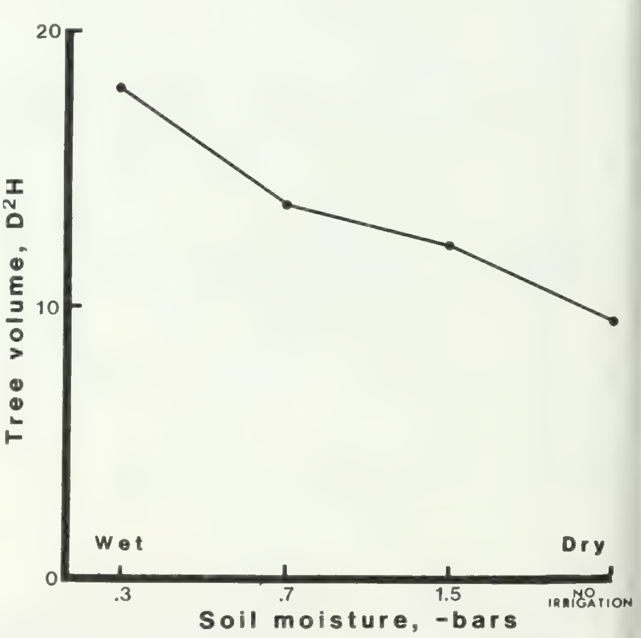

Figure 19.—*Relation of the tree volume index D^2H (where D is the breast height diameter and H is tree height) to maximum soil moisture tension permitted before irrigating. Data are from the 2-year-old clone NC-9922 with three replications.*

occupy the site, and soil moisture may become limiting. Then, little can be done to manage soil moisture. Without irrigation, soil moisture deficits in northern Wisconsin occur regularly in mid- to late summer (Hansen, unpublished data). Trees under water stress are more susceptible to diseases (Haywood and McNabb 1979) and insect pests (Stark 1975) and these can contribute to the decline or death of trees even after moisture is restored.

Data were collected during two summers of near normal precipitation in plantations with few weeds and in which the tree canopies had not yet closed (fig. 19). Under these conditions irrigation was highly beneficial to tree growth. Irrigation will probably have an even greater impact in dryer years, in weedy plantations, and in these plantations in the future now that the canopies have been closed. Another benefit is that morning irrigation can reduce populations of the cottonwood leaf beetle, some aphids, and some mites.

Although irrigation is expensive, sewage or industrial effluent can be used to satisfy the dual objective of tree irrigation and waste disposal (Hansen *et al.* 1980). This could provide additional economic benefits beyond just fiber production and make irrigation a feasible option.

Spacing

BIOMASS

Selection of a given spacing—within reasonable limits—will have only minimal, if any, effect of sustained biomass yield as long as the important principle of harvesting when the mean annual biomass increment culminates is observed. Adequate evidence has accumulated over the last decade on the so-called principle of "biomass production independence of spacing" which simply means that the same biomass yield can be obtained in plantations with a wide range of densities (Zavitkovski 1981b).

In the following discussion we will assume that the same quantity of stem-branch biomass can be produced in dense and open ICHP plantations, spaced from about 1 x 1 to 20 x 20 feet. Studies of Ek and Dawson (1976) suggested that the mean annual biomass production of dry weight of stems and branches in northern Wisconsin could reach 6.7 tons per acre per year. Because these quantities were determined in small plots with unplanted plot borders (Zavitkovski 1981a), this value may be an optimistic estimate but perhaps can be reached in large plantations of more productive hybrid poplar clones such as NE-299 (NC-5331) or NC-9922, which appear to be well adapted to the severe climate of the region.

WEED CONTROL

The duration required for weed control is determined primarily by tree spacing. In dense plantations canopies usually close during the second growing season and thus shade out the weeds so no weed control is required beyond the first year. In non-irrigated and nonfertilized plantations with rows 10 feet apart weed control by cultivation or herbicides may be required for several years. Here weed control is done primarily to reduce soil moisture and nutrient use by weeds. This is the standard practice in the industrial plantations in Ontario scheduled for rotation cycles of about 10 years (Raitanen 1978).

ESTABLISHMENT COSTS

Plantation establishment costs are composed of (1) various site preparation operations, which are the same for any spacing, and (2) the planting operation, a major cost of which is planting material—cuttings. Planting materials for dense plantations may add substantially to the total cost. For example, at a 3.3 x 3.3 foot spacing, 4,000 cuttings are planted per acre; at a 6.6 x 6.6 foot spacing only 1,000 cuttings are needed. At a price of 15 per cutting, costs per acre for the planting material alone are $600 for the 3.3 x 3.3 foot planting and $150 for the 6.6 by 6.6 foot planting. The cost of the planting operation itself also increases for dense plantations but no experimental data are available at this time. Part of the additional cost to establish dense plantations may be recovered because they require a shorter period of weed control.

ROTATION

In general, on the same site or under the same cultural treatments, as spacing increases–so does rotation length. Studies with *Populus* 'Tristis #1' indicated that in dense plantings, e.g., 9 x 9 inches, the mean annual biomass increment culminates at an age of about 3 years (Ek and Dawson 1976) but in more open stands, e.g., 8 x 8 feet, the maximum was not reached yet at age 9 (Zavitkovski, unpublished data).

TREE SIZE

As the spacing and rotation length increase, the size of the final crop trees also increases. For example, the average height and d.b.h. of the 3-year-old trees in the 9 x 9 inch planting were about 11 feet and 1 inch, respectively (Ek and Dawson 1976). The corresponding values for the 9-year-old trees in the 8 x 8 foot planting were 38 feet and 4.5 inches (Zavitkovski, unpublished data).

BIOMASS DISTRIBUTION

Spacing and age affect biomass distribution between stems and branches, and wood and bark and therefore affect the quality of the material produced. In general, the percentage of stem biomass increases with decreasing spacing and with age (table 8). In dense stands, e.g., 1 x 1 foot, stems accounted for about 75 percent of the total woody biomass in stands from 3- to 5-years-old. In widely spaced stands, e.g., 8 x 8 feet, stem biomass increased from 53 to 57 percent from age 3 to 5 and reached 65 percent in the 9-year-old stand.

Spacing also affects percentage of bark on stems and branches. For both components, percentage of bark decreases with wider spacing and with age (table 8). For example, at age 5, stem bark percentage in plantings spaced from 1 x 1 to 8 x 8 feet ranged from 20 to 14 percent and that of branches from 41 to 30 percent. At age 9 in the 8 x 8 foot planting, stem bark accounted for 12 percent of the total stem biomass and branch bark for 30 percent of the total branch biomass.

NUTRIENT REMOVALS

Tree spacing affects both tree size and rotation age and consequently nutrient concentration and total quantity of nutrients removed at harvest (Hansen and Baker 1979). In particular removal of N, and to a lesser extent P and K, can be reduced with longer rotations. For example, nitrogen concentration in the above-ground biomass of 9-year-old NC-5260 was only one-third that in 2-year-old trees of the same clone (Hansen, unpublished data). So wider spacings and longer rotations will drain less nutrients.

HARVESTING COSTS

Harvesting costs of dense plantations will be higher than that of open stands. Mattson (unpublished report dated 1976) calculated that efficiency of existing whole-tree chipping systems (visualized for harvesting of ICHP plantations) increases with wider spacing. The total cost of whole-tree harvesting, expressed in dollars per dry ton harvested, would be about three times higher in dense plantations (2 x 2 feet) than in open plantations (12 x 12 feet). For this calculation, Mattson assumed (from Ek and Dawson 1976) that both plantations will have the same biomass at age 10 but the dense plantation would have 33 times more trees than the open one. Our studies indicate that a different situation may develop in the harvesting of the two stands. The dense planting would be harvested several times (about 3 times) while the open plantation only once to accumulate the same stem-branch biomass. Under this system, the economic disparity may be even greater unless new harvesting-chipping machines being developed will substantially reduce harvesting costs in ICHP plantations.

Table 8.—*Biomass distribution among tree components of ICHP in Wisconsin*[1]

Spacing (ft)	Age	Woody biomass		Stems		Branches	
		Stems	Branches	Wood	Bark	Wood	Bark
	Years	Percent					
1 x 1	3	74	26	75	25	56	44
	4	76	24	79	21	58	42
	5	78	22	80	20	59	41
2 x 2	3	63	37	78	22	60	40
	4	72	28	81	19	60	40
	5	77	23	83	17	61	39
4 x 4	3	53	47	79	21	64	36
	4	64	36	83	17	65	35
	5	69	31	85	15	65	35
8 x 8	3	53	47	78	22	67	33
	4	56	44	84	16	69	31
	5	57	43	86	14	70	30
	9	65	35	88	12	70	30

[1]Based on Meldahl's (1979) PhD Thesis and on measurements and calculations of the authors.

The foregoing discussion indicates that the decision of "which spacing" should be made after considering a number of factors. No one spacing will be best for all cases. From the economic standpoint, not only plantation establishment but also harvesting will be less expensive in open plantations. The longer rotation cycles may have an additional advantage in reducing both soil compaction and the impact on site fertility.

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PESTICIDE PRECAUTIONARY STATEMENT

Pesticides used improperly can be injurious to man, animals, and plants. Follow the directions and heed all precautions on the labels.

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Apply pesticides so that they do not endanger humans, livestock, crops, beneficial insects, fish, and wildlife. Do not apply pesticides when there is danger of drift, when honey bees or other pollinating insects are visiting plants, or in ways that may contaminate water or leave illegal residues.

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If your hands become contaminated with a pesticide, do not eat or drink until you have washed. In case a pesticide is swallowed or gets in the eyes, follow the first-aid treatment given on the label, and get prompt medical attention. If a pesticide is spilled on your skin or clothing, remove clothing immediately and wash skin thoroughly.

Do not clean spray equipment or dump excess spray material near ponds, streams, or wells. Because it is difficult to remove all traces of herbicides from equipment, do not use the same equipment for insecticides or fungicides that you use for herbicides.

Dispose of empty pesticide containers promptly. Have them buried at a sanitary landfill dump, or crush and bury them in a level, isolated place.

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Hansen, Edward; Moore, Lincoln; Netzer, Daniel; Ostry, Michael; Phipps, Howard; Zavitkovski, Jaroslav.
Establishing intensively cultured hybrid poplar plantations for fuel and fiber. Gen. Tech. Rep. NC-78. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1983, 24p.

This paper describes a step-by-step procedure for establishing commercial size intensively cultured plantations of hybrid poplar and summarizes the state-of-knowledge as developed during 10 years of field research at Rhinelander, Wisconsin.

KEY WORDS: Intensive forestry, biomass plantations, energy plantations, maximum yield.

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General Technical Report **NC-79**

A Description of STEMS

The Stand and Tree Evaluation and Modeling System

David W. Belcher, Margaret R. Holdaway, and Gary J. Brand

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1982

FOREWORD

In 1975, research was begun at the North Central Forest Experiment Station to develop a system that would update, project, and analyze forest resource information in the North Central Region. This comprehensive evaluation system, designed to analyze all forest resources and their uses as an integrated system, is known as FREP (Forest Resources Evaluation Program).

STEMS (Stand and Tree Evaluation and Modeling System) is the tree growth projection component of FREP. This component has also been known as TRES, FREP, and FREP78. Today's STEMS is the product of a team of researchers at the North Central Station; the development of STEMS contintues.

This publication is one of three designed to acquaint you with different aspects of STEMS. A Description of STEMS, the User's Guide to STEMS, and A Programmer's Guide for STEMS make up the set.

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A DESCRIPTION OF STEMS— THE STAND AND TREE EVALUATION AND MODELING SYSTEM

David M. Belcher, *Biometrician,*
Margaret R. Holdaway, *Mathematical Statistician,*
and **Gary J. Brand,** *Mensurationist*

Long range planning is an essential part of all forest resource management. Prudent management requires accurate estimates of both current resource levels and the expected resource changes from implementing various management alternatives. Such information is required by law at State and Federal levels. For private industry, the commitment of capital requires estimates of present and future resource levels that are at least as accurate as those mandated by legislation.

Even with our rapidly expanding expertise in inventory procedures, our estimates of present and future resource levels have numerous voids. Sampling techniques capable of providing accurate estimates of current forest resource levels are available (Cochran 1977, Prodan 1968, Husch *et al.* 1972) but it is seldom practical to reinventory the forest every time current information is needed. Furthermore, resource inventories furnish no indication of future changes that could result from implementing various management alternatives. Therefore, a desirable goal is a resource management system that will add a dynamic dimension to the inventory process through simulation.

Most work in the area of forest resource simulation has been concentrated on timber projections and many excellent growth and yield models have been developed (Fries 1974, Fries *et al.* 1978). However, most of these models have been restricted to one or a few species groups in a relatively narrow geographic region. This segmented wealth of knowledge is of only limited value to the forest manager who must deal with all species and all forest resources, often over a broad geographical expanse. In recent years more emphasis has been placed on constructing comprehensive simulators that can better portray the dynamics of a diverse resource base. Still, the economically unimportant species, mixed stands, and forest resources other than timber have received little attention.

As a result of these many needs, the development of the Forest Resources Evaluation Program (FREP) was undertaken by the North Central Forest Experiment Station, USDA Forest Service, in 1975. The ultimate goal of the FREP project is to achieve the ability to simulate changes in all major forest resources. The value of such a projection system is twofold. First, it provides a mechanism for the detailed **update** of previously inventoried resources to estimate current resource levels. Second, it allows the detailed **projection** of future resource levels based on known or estimated current levels. Projections with and without silvicultural treatments can be made to provide the basis for resource assessment. Updates and projections for large geographic regions and a diversity of resource conditions can be made.

The first forest resource chosen was timber because of the wealth of information available in the literature and because a large amount of data on tree growth was readily accessible (Leary 1979).

Information about FREP and earlier versions of the tree growth projection system (TRES and FREP78) have been previously published (Buchman 1978, Lundgren 1978, Lundgren and Essex 1978, USDA Forest Service 1979, Hahn *et al.* 1979, Smith and Raile 1979). A short version of STEMS has also been produced (Brand 1981a).

This paper describes the computer program STEMS (Stand and Tree Evaluation and Modeling System), the current version of the tree growth projection system. It presents the program structure, discusses the growth model components, the management subsystem, and the regeneration subsystem. Some preliminary results of model testing are also presented and an example is discussed.

STRUCTURE OF THE STEMS SYSTEM

STEMS is a system of computer programs that projects the growth of individual trees in stands. Based on biological principles of forest growth, STEMS offers a flexible, generalized approach to simulating the change of forest trees in stands. Coefficients for its generalized diameter growth and mortality functions have been developed from more than 2,500 permanent remeasured plots for all the major tree species in the Lake States region of the United States.

STEMS is an individual-tree, distance-independent model that can provide much detail about trees and stands. Because each tree is projected individually (as a member of a competing community of trees), the system offers the user the opportunity to tailor output and silvicultural treatment subroutines to meet his specific objectives. User control of management options and output summaries further serves to make STEMS suitable to a variety of user needs. Changes for a single stand may be monitored in great detail and whole forest inventories may be projected.

STEMS consists of two FORTRAN programs—TGPS and TABL (fig. 1). The program TGPS (Tree Growth Projection System) "grows" stands of forest trees by simulating the birth, growth, harvest, and death of individual trees within a stand. Projection equations predict annual diameter growth of the tree, probability of mortality, and crown ratio. TGPS applies management action (removals) to the stands according to management guides developed for Lake States conditions (Brand 1979, 1981b). Regeneration of stands removed by management action is also provided. TGPS produces a standard output file of initial and updated tree lists for later summarization by TABL (TABLes) or other programs.

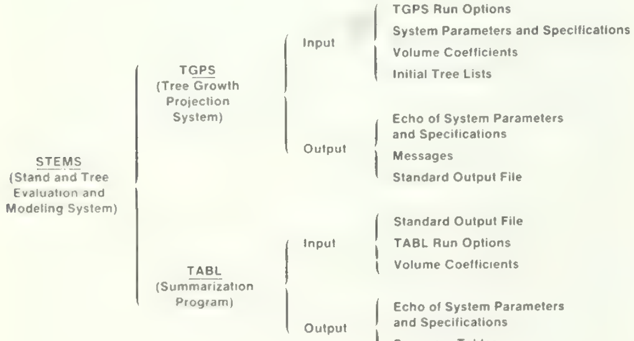

Figure 1.—*Organization of the STEMS system.*

Program TABL is available for summarizat the standard output file by species group and specified diameter class. The summary table sent the components of growth in terms of nu of trees per acre and basal area with optional volu

TGPS Program

Program TGPS consists of a series of subrou that perform the required input, processing, anc put (fig. 2). The first action of the program is t up the projection environment by reading the options, the system parameters and specificat and the volume equation coefficients with su tines SETRUN, SETSYS, and SETVOL, re tively. These subroutines and all others present this discussion are fully detailed by Belcher (1

The remaining subroutines compose the Plot cessor Loop. This loop is executed once for each on the input file or for a lesser number of plots appropriate run option is used. The first acti the Plot Processor Loop is to read an initial tre with Subroutine READ. Next, Subroutine TE examines the list to search for conditions like produce undesirable results further along in the gram. Informative messages are printed to des any problems that exist or corrective measures have been taken. The detail of these inform messages is controlled with another run optio

Next Subroutine WRITER is called. This su tine writes three types of information to the dard Output File (discussed in a later section) first is plot-specific information that does not ch during the projection period (e.g., property n site index, etc.). The second is the current tree and the third is a trailer record that indicate output is complete for this plot. At this point w the Plot Processor Loop only the plot-specific mation is written.

Subroutines SETSI computes site index by sp group. This technique is based on the work by mean and Vasilevsky (1971) and Carmean (19

Subroutine COVTYP sets the cover type fo plot by examining the current basal area of species group. This first call to COVTYP com the cover type for the initial tree list.

Subroutine WRITER is called next to writ initial tree list and stand conditions to the Sta Output File. Note that no projection has yet done. The initial tree list written here is the one entered with READ and is included in the o file for summarization purposes.

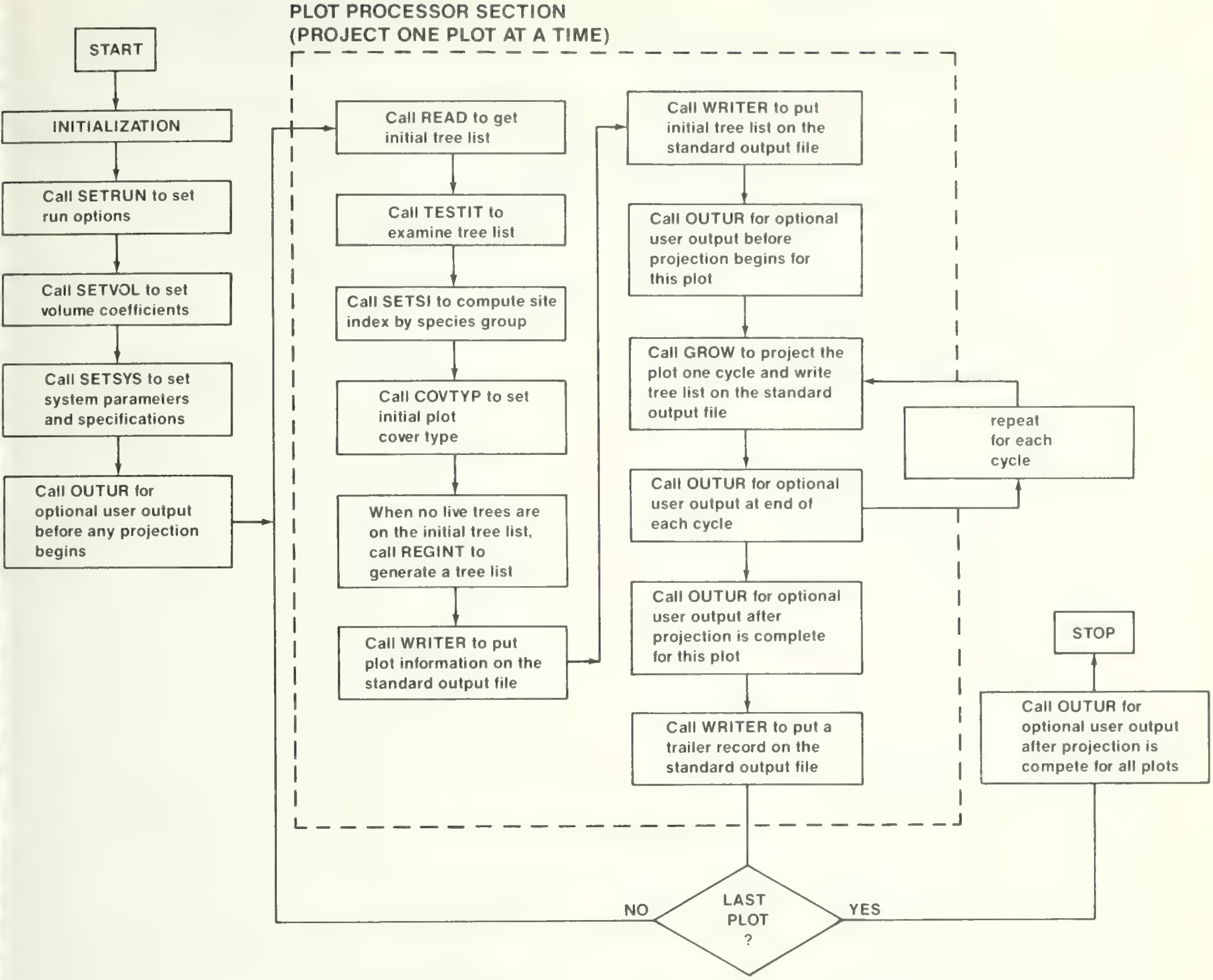
PLOT PROCESSOR SECTION
(PROJECT ONE PLOT AT A TIME)
START
INITIALIZATION
Call SETRUN to set run options
Call SETVOL to set volume coefficients
Call SETSYS to set system parameters and specifications
Call OUTUR for optional user output before any projection begins
Call READ to get initial tree list
Call TESTIT to examine tree list
Call SETSI to compute site index by species group
Call COVTYP to set initial plot cover type
When no live trees are on the initial tree list, call REGINT to generate a tree list
Call WRITER to put plot information on the standard output file
Call WRITER to put initial tree list on the standard output file
Call OUTUR for optional user output before projection begins for this plot
Call GROW to project the plot one cycle and write tree list on the standard output file
repeat for each cycle
Call OUTUR for optional user output at end of each cycle
Call OUTUR for optional user output after projection is complete for this plot
Call WRITER to put a trailer record on the standard output file
STOP
Call OUTUR for optional user output after projection is compete for all plots
NO
LAST PLOT ?
YES

Figure 2.—*Organization of TGPS, the tree growth processor.*

At this point, TGPS enters the Growth and Management Section, which is executed once for each of the cycles requested in the run options. The main feature of this section is a call to Subroutine GROW that "grows" the plot for one cycle by applying a sequence of 1-year projections of growth and mortality. If management is desired, it is performed at the requested point within the cycle by calls to Subroutine MANAGE. If regeneration is required, it is applied at the appropriate point. The projected tree list is written to the Standard Output File by Subroutine WRITER from within GROW.

When the Growth and Management Loop has completed all of its cycles, the projection of the current plot is complete. WRITER is again called to write a record on the Standard Output File to indicate the end of the plot projection. This also signals the end of the Plot Processor Loop and control returns to READ to enter the next plot to be projected.

When all the plots to be projected are complete, a final call to WRITER is made to print the format used for the Standard Output File. This is the format to be followed if the user will summarize the Standard Output File tree lists with his own summarization program.

Throughout the program, TGPS provides calls to Subroutine OUTUR. This subroutine consists only of the common block and RETURN statement. Use of OUTUR is optional but is included as a place for inserting user-written code to do summarization, output, or any further processing.

TABL Program

Program TABL (fig. 3) summarizes the standard output file produced by TGPS. The program first reads the TABL run options, system specifications, and volume equation coefficients. Then the Plot Processor Loop is entered and the plot specific information is read for the first plot. Next a tree list is read, and subroutine SETIT organizes calls to subroutine SUMARY to compute the current plot conditions and to subroutine TABLE to print a plot summary. The read-summarize-print loop is repeated until all information is printed for the current plot. Then the next plot on the standard output file from TGPS is processed.

When all plots have been processed, summaries of all plots combined may be printed. The types of tables printed and the details of each are controlled by TABL run options (for more detail on the summarization and tabling process see Belcher 1981).

GROWTH MODEL COMPONENTS

The STEMS tree growth simulation model consists of four components: (1) a function that estimates the potential annual diameter growth of an individual tree, (2) a modifier function to reduce the potential growth because forest-grown trees may be competing for limited resources and therefore not reach their potential growth, (3) a mortality function, and (4) a crown ratio function.

Potential Function

Potential diameter growth is the annual diameter increment for a tree in a forest stand free to grow without competition from its neighbors.

A basic premise in the design logic of this forest growth projection system is that the growth of a tree can be represented by a multiplicative combination

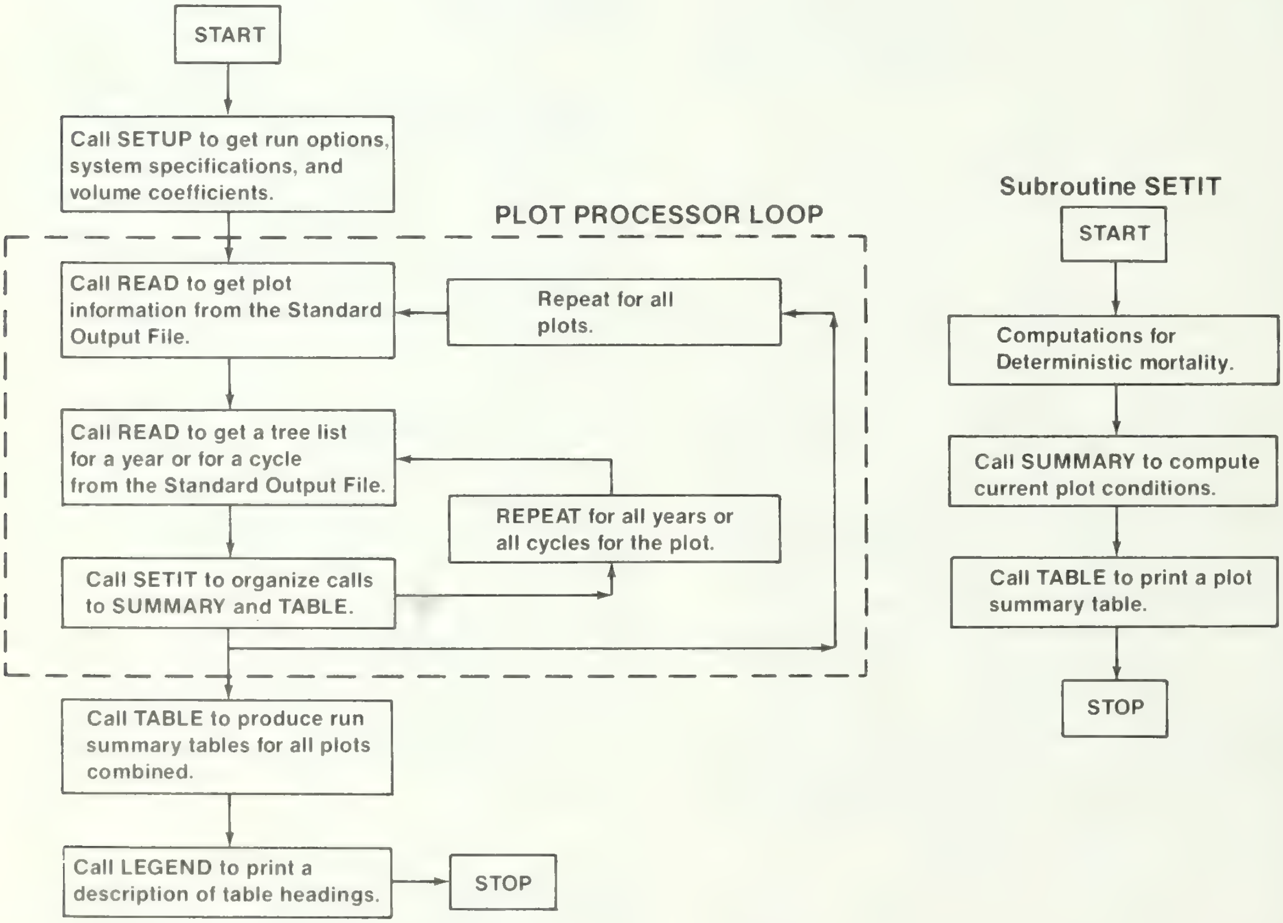
START
Call SETUP to get run options, system specifications, and volume coefficients.
PLOT PROCESSOR LOOP
Call READ to get plot information from the Standard Output File.
Repeat for all plots.
Call READ to get a tree list for a year or for a cycle from the Standard Output File.
REPEAT for all years or all cycles for the plot.
Call SETIT to organize calls to SUMMARY and TABLE.
Call TABLE to produce run summary tables for all plots combined.
Call LEGEND to print a description of table headings.
STOP
Subroutine SETIT
START
Computations for Deterministic mortality.
Call SUMMARY to compute current plot conditions.
Call TABLE to print a plot summary table.
STOP

Figure 3.—*Organization of TABL, standard summary routine.*

of a potential growth and a modifier of the potential due to competition. These two parts fit together as shown below:

$$\text{Annual change in tree diameter} = \left[\begin{array}{l}\text{Potential annual}\\ \text{d.b.h. growth}\end{array}\right] \times \left[\begin{array}{l}\text{Fraction of the potential}\\ \text{growth actually occurring}\end{array}\right]$$

Following is the potential diameter growth function used in STEMS (Hahn and Leary 1979):

$$\text{Potential annual diameter growth rate} = b_1 + b_2 D^{b_3} + b_4 \, SI \; CR \; D^{b_5}$$

where:

D = initial tree d.b.h.;
SI = plot site index;
CR = tree crown ratio code;
$b_1 - b_5$ = species specific regression coefficients.

Data used to fit this model came from two successive measurements made on 51,149 dominant and codominant trees of 26 species groups throughout Michigan, Minnesota, and Wisconsin (Christensen *et al.* 1979). Variables measured for each tree included diameter, crown ratio code[1] at the last measurement, and plot site index.

Work by Carmean (1979) and Carmean and Vasilevsky (1971) has provided a means for predicting the site index for each species group from the plot site index. In the current version of STEMS, species site index rather than plot site index is used in the potential function.

A graph of potential growth for the black and green ash species group shows that a tree with a diameter of 10 inches, site index of 60, and crown ratio code of 3 would have a potential growth of about 0.15 inch per year (fig. 4). As site index increases, potential growth increases. However, potential growth peaks between 15 and 20 inches d.b.h. regardless of site index.

Modifier Function

The modifier function in the original version of the projection system used a stand component approach (Leary and Holdaway 1979). In STEMS, the function has evolved into an individual tree modifier (Hahn *et al.* 1979). The current form as developed by Holdaway[2] and used in STEMS is:

$$\text{MODIFIER} = 1 - e^{-B_o \left[\frac{BA_{max} - BA}{BA}\right]^{.5}}$$

where:

BA_{max} = maximum basal area per acre expected for the species;
BA = current basal area per acre;
B_o = $f(R) \cdot g(AD)$;
R = relative d.b.h. of the tree (ratio of the tree's d.b.h. to the average stand diameter);
AD = average stand diameter;
$f(R)$ = a function characterizing the individual tree's relative diameter effect on the modifier $f(R) = b_1 [1\text{-}e^{b_2R}] b_3 + b_4$;
$g(AD)$ = a function characterizing the average stand diameter effect $g(AD) = c_1 (AD + 1)^{c_2}$; and
$b_1, b_2, b_3, b_4, c_1, c_2$ = regression coefficients.

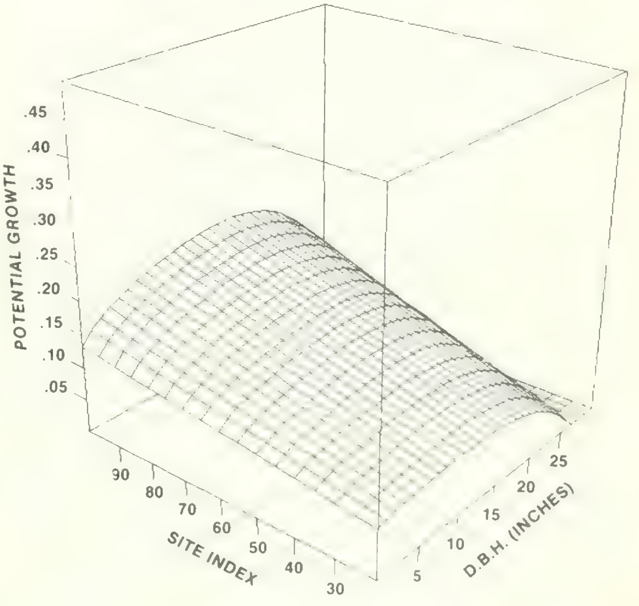

Figure 4.—*Potential annual diameter growth (in inches) for the black and green ash species group with crown ratio code = 3.*

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[1] *See the section on crown ratio function for a definition of the crown ratio code.*

[2] *Reported in unpublished manuscript by Margaret Holdaway, Mathematical Statistician, North Central Forest Experiment Station, St. Paul, Minnesota.*

Trees on less dense stands keep a higher percentage of their potential growth than those on dense stands (fig. 5). For example: a 10-inch tree on a stand with average diameter of 8 inches (relative diameter = 10/8 = 1.25) and with plot basal area of 100 ft²/acre realizes only about 70 percent of its estimated potential growth.

The results of the potential and modifier functions can be combined to produce a realized growth function (fig. 6). Consider a green ash tree with a 10-inch diameter and crown ratio code of 3, growing in a stand with a site index of 60, average diameter of 8 inches, and plot basal area of 100 ft²/acre. The potential function estimates an annual growth of 0.15 inch, but the modifier estimates that only 70 percent of that growth will occur so the realized growth for this tree is 0.10 inch.

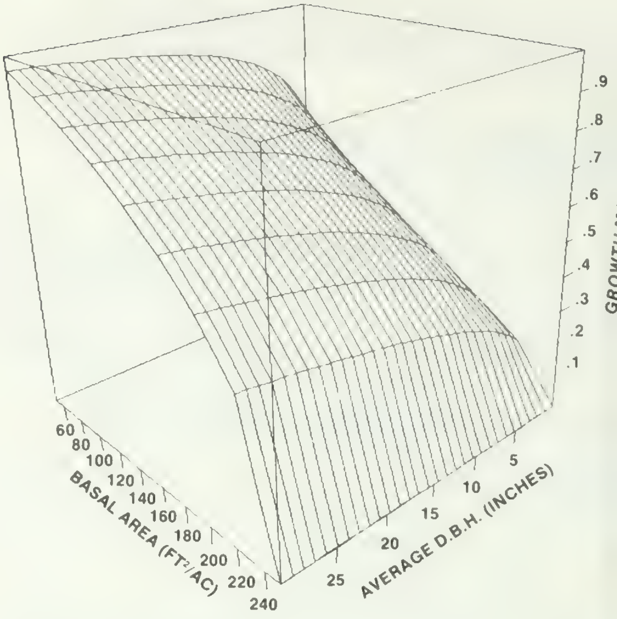

Figure 5.—*Growth modifier function for the bla and green ash species group with relative diamet = 1.25.*

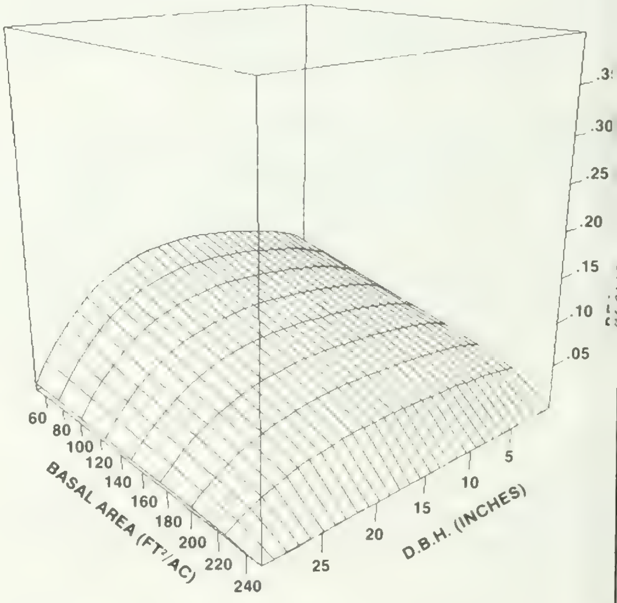

Figure 6.—*Realized annual growth for the black a green ash species group for trees with crown ra code of 3 in a stand with site index of 60 and a erage diameter of 8 inches.*

Mortality Function

The process of natural mortality in a forest stand is simulated by applying the mortality function developed by Buchman (1979). This function predicts the probability of death of an individual tree during a 1-year period as a function of the tree's current d.b.h. and its annual growth rate.

The form of the equation is:

$$P = \left[1 + e^{(b_1 + b_2\, DGR^{b_3} + b_4 D)}\right]^{-1} + b_5$$

where:

P = estimated probability of a tree dying;
b_1 = adjustment for diameter effect when DGR is zero;
b_2, b_3 = adjust probability of dying based on DGR;
DGR = annual diameter growth rate in inches;
b_4 = adjustment based on tree size;
D = diameter at breast height in inches; and
b_5 = background annual death rate.

The regression coefficients—b_1, b_2, b_3, b_4, and b_5—were determined separately for each species group.

A graph of the mortality function for black and green ash shows it is unlikely that a tree will die if its growth rate is greater than 0.08 inch per year (fig. 7). A tree with a growth rate of 0.10 inch per year has less than a 1 percent chance of dying.

STEMS provides two ways to assign mortality to individual trees. The options are known as probabilistic and deterministic mortality and are selected by the appropriate TGPS run option. The difference between the two options is the way the mortality factor is applied. For probabilistic mortality, a ra dom number is drawn from a uniform distributic between 0 and 1. If the probability of death is great than this random number, the tree and all the tre that it represents are marked as dead. For dete ministic mortality, the number of trees per acre th

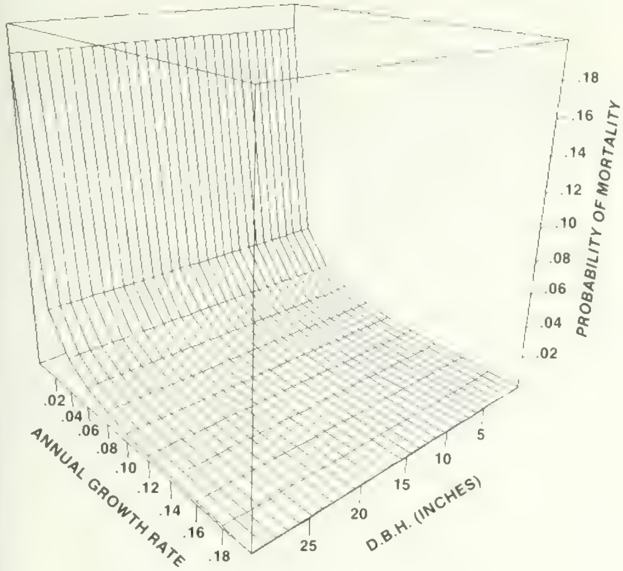

Figure 7.—*Annual probability of mortality for the black and green ash species group.*

this tree represents is reduced by the proportion predicted by the mortality function. When a tree's expansion factor is reduced to 1, mortality type reverts to probabilistic so that a tree on the tree list will not represent less than one tree per acre.

Each type of mortality has advantages and disadvantages and it is up to the user to decide the option appropriate to his situation. For large numbers of plots and short projections (less than 30 years), the two options produce the same results. Probabilistic mortality is more computationally efficient than deterministic but for long projections it can have undesirable results. A plot may be reduced through mortality or cutting to two or three entries on the tree list and each tree on the list represents about one-half or one-third of the basal area per acre. If one of these trees dies, the plot loses a large portion of its basal area at once. This may not be a reasonable representation of natural mortality. The deterministic option does not have this problem because it retains the tree list entries for a much longer period. However, more computations are required and annual output of tree lists is necessary when a summary of growth components is desired. For large numbers of plots the size of the output file can become critical. The probabilistic option produces a shorter output file for the same components of growth summaries.

Crown Ratio Function

To allow the model to respond to changes in stand density and to allow the potential function to be used when crown ratio was not measured, a crown ratio code function has been developed to estimate crown ratio codes according to stand basal area and individual tree d.b.h. The code 1, 2, ..., 9, 0 represents crown ratios of from 1 to 10 percent, 11 to 20 percent, ..., 81 to 90 percent, and 91 to 100 percent, respectively. Application of this function makes crown ratio a dynamic variable within the simulation program and thus increases the precision of projections. The function can also be used to compute an initial crown ratio code for those trees for which crown ratio was not measured.

The crown ratio code function used in the original version of the growth projection system predicted mean stand crown ratio code (Holdaway *et al.* 1979). Subsequent development[3] has resulted in the following individual tree crown ratio code function now used in STEMS (fig. 8):

$$CR = \frac{b_1}{1 + b_2\,BA} + b_3\left[1 - e^{-b_4 D}\right] + CF$$

where:

CR = individual tree crown ratio code;
BA = 10-year running average stand basal area per acre;
D = current tree diameter (d.b.h.);
CF = correction factor computed as: initial predicted CR–initial observed CR; and
b_1, b_2, b_3, b_4 = species specific regression coefficients.

The model was calibrated using current stand basal area for the BA term but STEMS uses a 10-year running average stand basal area for this term. This usage produces a desirable lag in the function's response to drastic changes such as thinnings.

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[3] *Documentation for the crown ratio code function is currently being prepared by Margaret Holdaway, Mathematical Statistician, North Central Forest Experiment Station, St. Paul, Minnesota.*

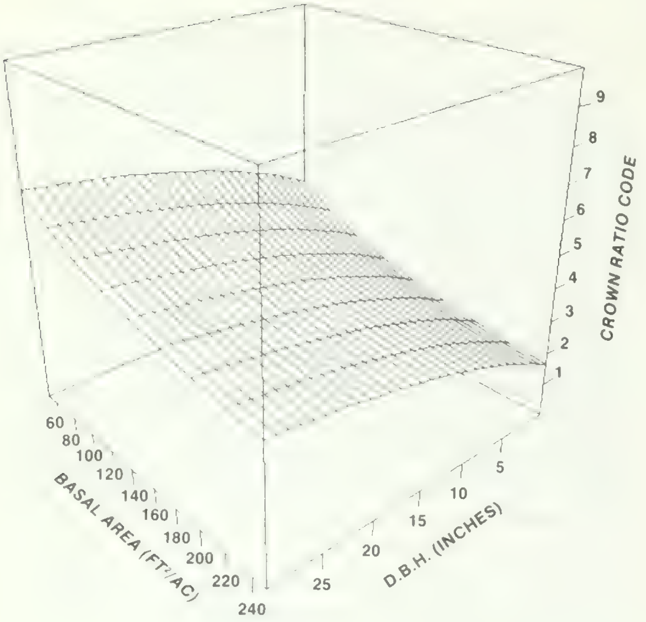

Figure 8.—*Crown ratio code for the jack pine species group.*

MANAGEMENT SUBSYSTEM

The projection system contains a set of generalized management guides and marking rules (Brand 1979, 1981b). Including management guides allows simulated tree cutting and thereby a means to project managed stands. Three operations are necessary to simulate timber management: assigning a management guide, determining the appropriate treatment according to that guide, and removing trees to carry out the selected treatment.

The first step in assigning a management guide is to determine the plot cover type by examining the basal areas of trees of each species group. To do this, various combinations of species group basal areas are compared to determine the group with the largest basal area. The combination with the largest basal area is then split into smaller groups that are then compared. This process is continued until a single species or a small group of species remains to represent a cover type. For example, red pine cover type is represented by red pine species, but northern hardwood cover type is represented by any combination of sugar maple, basswood, hemlock, and yellow birch species. The user specifies the management guide to be used for each cover type via input from the system parameters and specifications file.

When the management guide has been assigned the plot characteristics are used to select the appropriate silvicultural treatment—clearcut, thin, d nothing, etc. Management guides recently developed by North Central Forest Experiment Station scientists were used to select treatments for most of th cover types (Benzie 1977a, 1977b; Johnston 1977a 1977b; Perala 1977; Sander 1977; Tubbs 1977). Additional sources were used for other types and additional clarification (USDA Forest Service 1958, 1967 1979).[4] When plot characteristics are compared with the management guide, a recommended treatmen is produced. Rotation ages, residual basal areas, and the other characteristics used in the managemen guides can be easily modified to test the effect o alternative management strategies.

A marking rule was developed for each recommend treatment that requires trees to be cut. Thi marking rule produces a hierarchy of characteristic used to rank the trees on the plot in order of increasing "value," which is determined by species, diameter, and tree quality. The least "valuable" trees ar cut first. When the desired residual conditions exist no more trees are cut. The trees designated as cu still remain on the tree list but with a cut tree statu code. A marking rule can be easily changed to examine the effect of not removing cull trees, favorin alternative species, or favoring different size classes Brand (1979, 1981b) describes the management subsystem in more detail.

REGENERATION SUBSYSTEM

Regeneration in a forest growth simulator is th process of adding new trees to the system. This process can be divided into three categories for modelin purposes. The first category includes the small number of new trees that will become established eac year in almost every stand. These new trees wi differ as to species and most of them will die durin the first few years of their lives. Depending on th characteristics of the stand they enter, however, som may survive and become "permanent" component of the stand. The second category, "partial" regeneration, represents the new trees that normally enter a stand to fill spaces left by thinnings, heav mortality, or other occurrences that leave moderately sized holes in the existing stand. The third category, "initial" regeneration, represents the totally new stand that must be generated when the existing stand has been completely removed through clearcut or equivalent management action. This condition is common for forest types under even-aged management such as red pine and jack pine but is uncommon for forest types under uneven-aged management such as northern hardwoods.

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[4] *Personal communication with John Benzie, Richard Godman, William Johnston, and Donald Peral all scientists with the North Central Forest Experiment Station.*

We do not now have the data on which to base a function to model either the first or second category of regeneration. However, we have developed a model for "initial" regeneration. Simulation of "initial" regeneration consists of two steps. The first step is to determine the characteristics of the new stand—species groups present, number of trees, average diameter, etc. The second step is to generate a diameter distribution for the new trees. Only these two steps are discussed here.

Characteristics of the new stand are based on both previous stand's characteristics and the type of management used to remove the previous stand. Decision trees have been developed[5] for most of the major cover types that lead from the previous stand characteristics to those of the new stand. As an example, when a paper birch stand on a dry site is clearcut, the recommended regeneration technique is to prepare the site and plant 900 jack pine trees per acre (fig. 9). The resulting stand will have an average diameter of 1.5 inches when it enters the projection system and release will probably be required. If the previous stand had not been dry or if a shelterwood removal had been done rather than a clearcut, the new stand would have different characteristics.

When the new plot characteristics have been determined, a diameter distribution must be generated for the new trees. STEMS arbitrarily assumes a normal distribution of diameters about the average stand diameter. The normal distribution is probably not the best one for modeling a regenerated stand and we are currently trying to develop a more realistic method for generating the new diameters. However, we will use the normal distribution until this work is complete.

Currently STEMS assumes that any regenerated stand will enter the projection system 15 years after the previous stand is removed. In future versions of STEMS this number will be set in the decision trees.

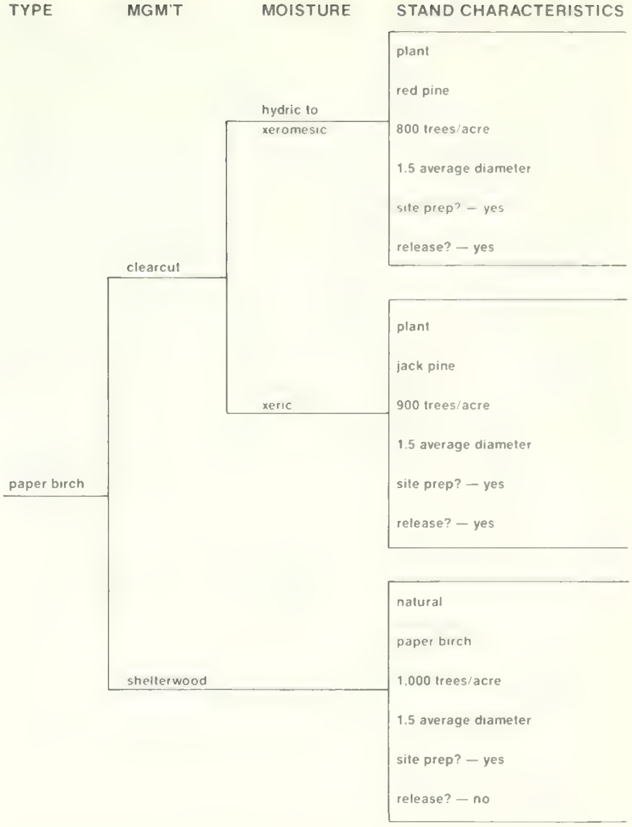

Figure 9.—*Decision tree for regenerating a stand that was previously paper birch.*

The user can easily change any of the values associated with the regeneration subsystem by modifying the system parameters and specifications data file (Belcher 1981).

TESTING STEMS

As each component of the system was developed, we tested it against the data used in development and against an independent data set using the usual indices of goodness of fit (R^2, distribution of residuals, and standard errors of estimates). Then, to determine how the system worked as a whole we subjected it to a second set of tests. First, the system was tested on the data used to develop the components to see if it could reasonably simulate the conditions used to develop it. Results from these tests do not appear here. Next, the system was tested on data not used in model calibration. Tables 1-3 were produced using this independent data set. The statistic used in this and further system tests was the ratio of predicted to observed means. The tests presented here follow the procedure outlined by Leary *et al.* (1979).

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[5] *Nancy Walters and Gary Brand of North Central Forest Experiment Station.*

Table 1.—*Ratio of predicted mean to observed mean*[1] *for average diameter, number of trees, and basal area by forest type for the Cloquet Experimental Forest*

Forest type	Plots	Years after initial measurement								
		5	10	17	5	10	17	5	10	17
	Number	*Average plot diameter*			*Number of trees*			*Basal area*		
Jack pine	79	1.00	1.00	1.00	1.00	1.01	1.04	1.00	1.01	1.04
Red pine	49	1.00	1.00	.99	1.00	.99	1.01	1.00	1.00	1.00
White pine	6	.99	.97	.96	1.05	1.12	1.16	1.03	1.06	1.06
White spruce	4	.99	1.03	.98	1.01	1.13	1.09	1.04	1.24	1.12
Balsam fir	23	1.02	1.03	1.06	1.04	1.09	1.19	1.09	1.18	1.31
Black spruce	29	1.02	1.03	1.06	1.05	1.08	1.16	1.07	1.13	1.29
Tamarack	19	1.01	1.02	1.03	.97	.92	.87	1.00	1.01	1.06
N. white-cedar	14	1.01	1.03	1.05	1.03	1.04	1.10	1.06	1.12	1.23
Lowland hdwds	3	1.00	1.02	1.01	1.07	1.06	1.28	1.08	1.11	1.32
Aspen	30	1.01	1.02	1.04	1.01	1.03	1.07	1.05	1.10	1.19
Paper birch	36	1.00	1.02	1.03	1.02	1.02	1.03	1.04	1.05	1.09
ALL	292	1.00	1.01	1.02	1.02	1.02	1.06	1.03	1.05	1.09

[1] Calculated as: $\frac{\text{predicted mean stand attribute for the type}}{\text{observed mean stand attribute for the type.}}$

STEMS was tested[6] on data from five areas within the Lake States (fig. 10):

(1) Cloquet Experimental Forest of the College of Forestry[7], University of Minnesota;
(2) Chequamegon National Forest, Wisconsin;
(3) Nicolet National Forest, Wisconsin;
(4) Hiawatha National Forest, Michigan; and
(5) Manistee National Forest, Michigan.

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[6] *Most of the work done on testing the STEMS program was done by Gary Brand and Margaret Holdaway with assistance from Stephen Shifley and Jerold Hahn, all of the North Central Forest Experiment Station, St. Paul, Minnesota.*

[7] *Dietmar Rose and the staff of the Cloquet Forestry Center made the past measurement data available and assisted in the 1976 measurements.*

Table 2.—*Summary of the ratio of predicted mean basal area to observed mean basal area by forest type for the measurement closest to 10 years for each of the five forest areas (The number of plots appear in parenthesis)*

Forest type	Cloquet (10 yrs)	Chequamegon (11 yrs)	Nicolet (11 yrs)	Hiawatha (9 yrs)	Manistee (11 yrs)	ALL
Jack pine	1.01 (79)	1.08 (7)	1.08 (6)	1.08 (20)	1.05 (15)	1.03(127)
Red pine	1.00 (49)	1.06 (6)	.93 (4)	.92 (11)	1.01 (15)	.99 (85)
White pine	1.06 (6)	1.00 (2)	.93 (2)	1.00 (3)		1.01 (13)
White spruce	1.24 (4)	.78 (1)	.99 (4)	.93 (1)		1.07 (10)
Balsam fir	1.18 (23)	1.06 (14)	1.08 (8)	1.39 (6)		1.15 (51)
Black spruce	1.13 (29)	.93 (2)	1.62 (3)	1.12 (6)		1.16 (40)
Tamarack	1.01 (19)	1.02 (2)	.77 (2)			.98 (23)
N. white-cedar	1.12 (14)	1.07 (8)	1.05 (9)	1.06 (14)	1.37 (2)	1.08 (47)
Hemlock			.93 (4)	.96 (3)		.95 (7)
Lowland hdwds	1.11 (3)	1.31 (5)	1.09 (2)	.92 (1)	1.47 (19)	1.34 (30)
Northern hdwds		1.05 (40)	1.01 (49)	.99 (28)	1.21 (18)	1.04(135)
White oak					.98 (15)	.98 (15)
Northern red oak		1.10 (4)	1.30 (1)	1.03 (2)	1.15 (8)	1.13 (15)
Oak-pine				.78 (1)	1.00 (9)	.47 (10)
Oak-hickory		.40 (1)			.82 (34)	.82 (35)
Aspen	1.10 (30)	1.07 (23)	.98 (42)	1.02 (14)	1.24 (12)	1.05(121)
Paper birch	1.05 (36)	.99 (8)	.99 (9)	1.22 (4)	1.10 (1)	1.05 (58)
ALL	1.05(292)	1.06(123)	1.01(145)	1.03(114)	1.09(148)	1.05(822)

Table 3.—*Summary of the mean of the plot ratios of predicted average diameter to observed average diameter by forest type for the Cloquet Experimental Forest*

Forest type	Plots	Years after initial measurement		
		5	10	17
	Number			
Jack pine	79	1.00	1.00	.99
Red pine	49	.99	1.00	.99
White pine	6	.99	.97	.97
White spruce	4	.99	1.03	.98
Balsam fir	23	1.02	1.04	1.06
Black spruce	29	1.02	1.03	1.06
Tamarack	19	1.01	1.03	1.05
N. white-cedar	14	1.01	1.03	1.05
Lowland hdwds	3	1.00	1.02	1.01
Aspen	30	1.02	1.03	1.05
Paper birch	36	1.01	1.02	1.04
ALL	292	1.01	1.01	1.02

Ratios were computed for plot average diameter, number of trees, and basal area to give a representative picture of system performance. In general, the whole system accurately predicted diameters but overpredicted basal areas per acre over periods ranging from 5 to 17 years.

As the number of plots increases and the number of years of projection decreases, the ratio of predicted to observed mean moves closer to one (table 1). For example: on the Cloquet Forest there were 49 plots of the red pine forest type and 6 plots of the white pine forest type. After 17 years of projection the ratio of predicted to observed mean average diameter was 0.99 for red pine—a 1 percent underestimate—but was 0.96 for white pine—a 4 percent underestimate.

A comparison of the ratio of mean stand basal areas by location indicates the variability between locations (table 2). For example, the predicted mean stand basal areas for the 14 aspen plots on the Hiawatha Forest show an overprediction of only 2 percent. In contrast, the 12 aspen plots on the Manistee Forest show a 24 percent overprediction.

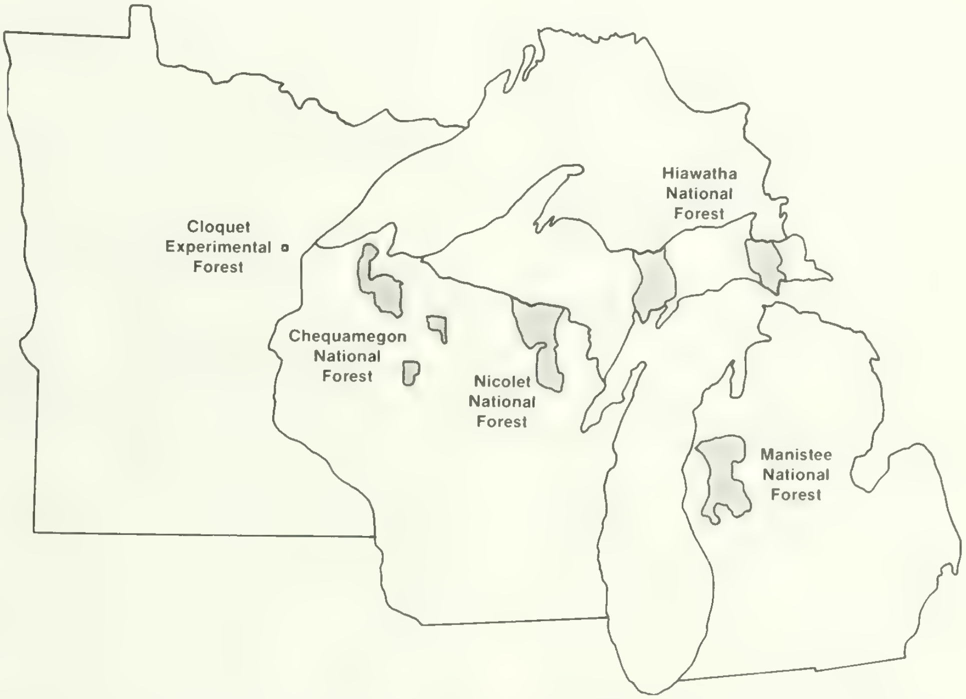

Figure 10.—*Location of areas where data were collected to validate the model.*

Tables 1 and 2 show ratios of mean stand characteristics, i.e.:

$$\text{ratio} = \frac{\frac{1}{n}\sum_{i=1}^{n} \text{predicted value}_i}{\frac{1}{n}\sum_{i=1}^{n} \text{observed value}_i}$$

where n is the number of plots on which the mean is based. Table 3, however, presents the mean of ratios of a stand characteristic, i.e.:

$$\text{mean} = \frac{1}{n}\sum_{i=1}^{n} \frac{\text{predicted value}_i}{\text{observed value}_i}$$

This later statistic allows computation of dispersion measures such as variance of the plot ratios about the mean of plot ratios. The mean of ratios of predicted to observed stand average diameter by forest type can also be graphed over time (fig. 11). Approximately 68 percent of the stand average diameter ratios are expected to fall within +1 and −1 standard deviation from the mean.

Another method of presenting dispersion of a characteristic being tested is to plot its cumulative frequency of errors.[8] A graph of this type for the four National Forests shows that basal area for 16 percent of the plots on these four forests was underpredicted by more than 10 ft^2 and for 23 percent of the plots was overpredicted by more than 10 ft^2 for a period of about 10 years (fig. 12). For the remainder of the plots, 61 percent, predicted basal area was within 10 ft^2 of the observed basal area.

The validation results presented in this discussion represent only a few of the tests that can be and are being done[9] to validate the model.

EXAMPLE USING STEMS

We will now present an example of how STEMS can be used. For this example, two 30-year projections have been made of sample plots representing the Nicolet National Forest. One projection is made with management applied (full silvicultural prescription with timber harvesting) and the other is made with no management (no timber harvesting). No constraints will be placed on when the forest can be managed. That is, should the STEMS management guides call for all plots to be harvested in the same year, that will be done. This will allow us to compare between two management extremes.

The plots providing the data were last measured in 1975. To begin the 30-year projections with more current conditions, the 1975 survey has been updated to 1979, the last year for which actual removals were known. The updating procedure involves beginning with the 1975 survey and estimating growth and mortality with the projection system while selecting trees to cut to approximate the observed volume removed from the forest (Smith and Raile 1979).

The following plot and tree variables were read from a forest survey file to produce an initial tree list:

Tree data	**Plot data**
Species	Property number
D.b.h.	Plot number
Crown ratio	Site index
Tree class (desirable, acceptable, rough, rotten)	Stand age
Number of trees/acre represented by the sample tree	Cover type Acreage represented by plot Measurement year

All variables are required by the projection system except property number, plot number, cover type and plot acreage.

All volumes used in this example were computed from individual tree characteristics using equations and coefficients developed for northeast Minnesota (Raile 1981). These equations were chosen instead of the local volume equations available for Wisconsin (the Nicolet National Forest is in Wisconsin) because the Minnesota equations contain a site index term and the Wisconsin equations do not. We believe including the site index term will make the computed volumes more accurate even though the equations were developed for a different geographical region.

Many types of summaries and displays can be developed from the tree lists produced by STEMS. For this example, we will present information on acreage and volume of growing stock, cut and mortality volumes, trends in species composition, and size distribution.

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[8] *This approach was suggested by Steven Shifley, North Central Forest Experiment Station.*

[9] *Gary Brand and Margaret Holdaway, North Central Forest Experiment Station, are currently performing a comprehensive validation scheme for the projection system.*

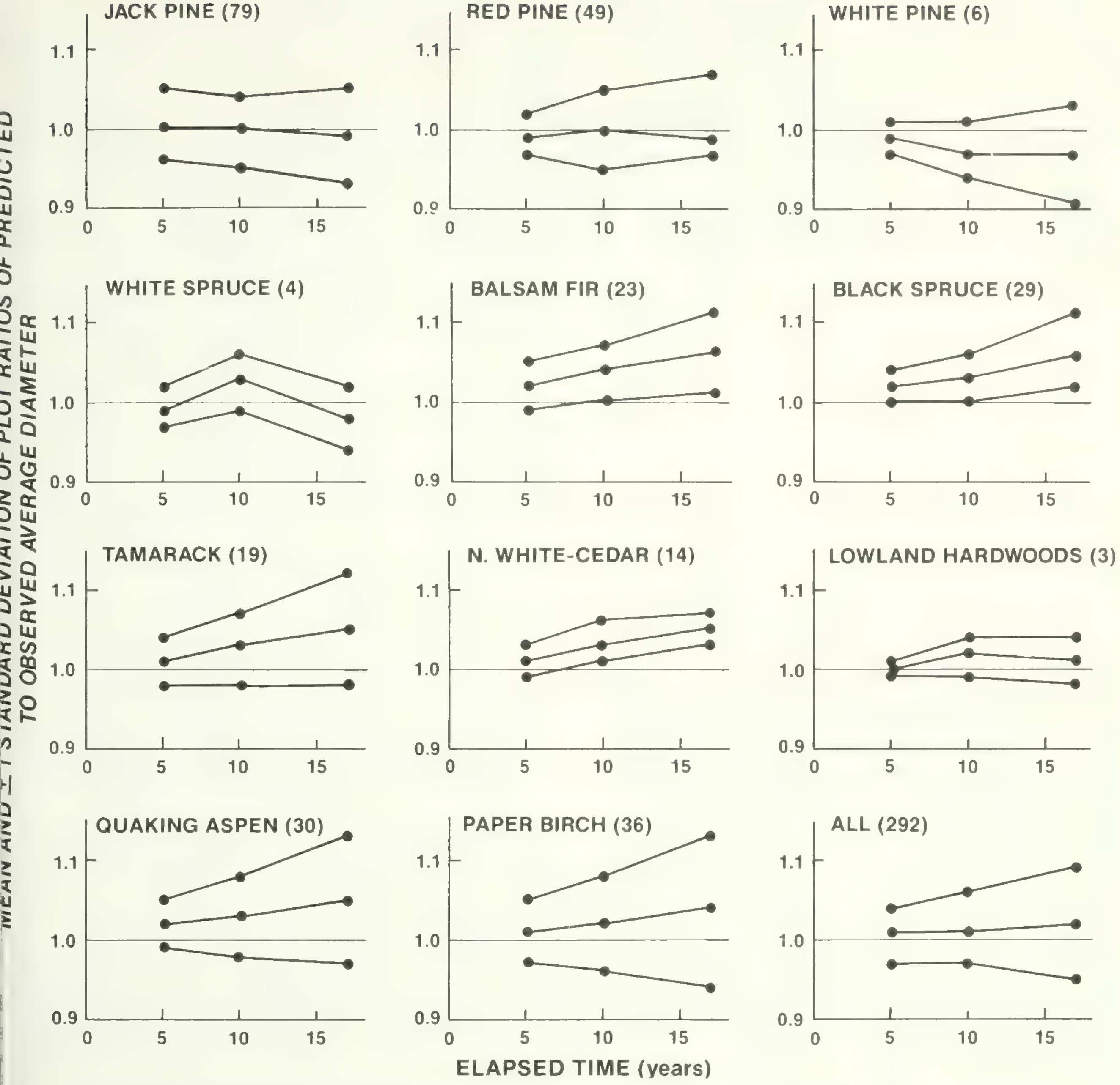

Figure 11.—*Pattern of mean and standard deviation of plot ratios of predicted to observed average diameter by forest types on the Cloquet Experimental Forest, Minnesota. Standard deviations are shown by the outer lines. Number of plots shown in parentheses.*

Acreage and volume of growing stock for 1979 hrough 2009 are presented for the Nicolet National 'orest with management applied and with no mangement (tables 4 and 5). The distribution of area hanges because STEMS reclassifies the cover type f stands that have sufficient change in species composition. Species composition can change by loss of rees due to mortality, cutting, and by regeneration 'f stands to different species groups.

The overall growth rate for the 30-year period is less when the management guides are applied than when management is not used (fig. 13). This is because the management guides select for value of the forest rather than for volume. Thus, the more valuable species, such as red pine, are preferred over the faster growing species, such as aspen.

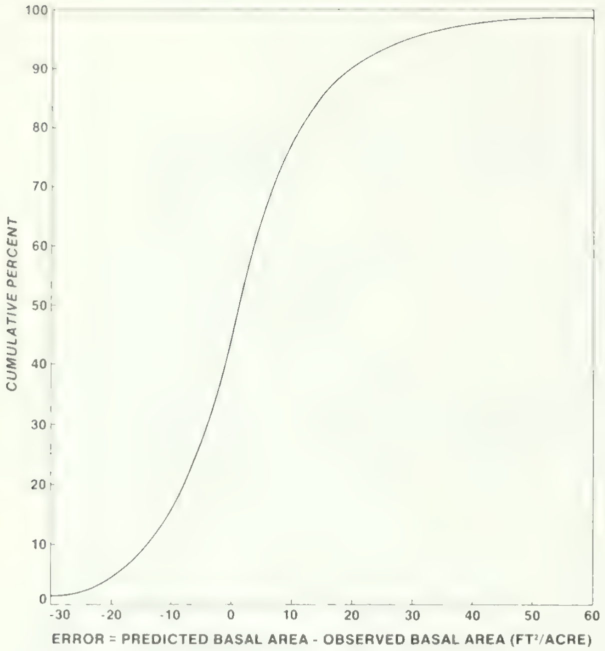

Figure 12.—*Cumulative frequency of errors in predicting basal area for four National Forests. The measurement interval was approximately 10 years.*

The STEMS management guides recommended that 343.1 million cubic feet of growing stock trees be cut during the 30-year projection period (table 6). Because low value and poorly growing trees would

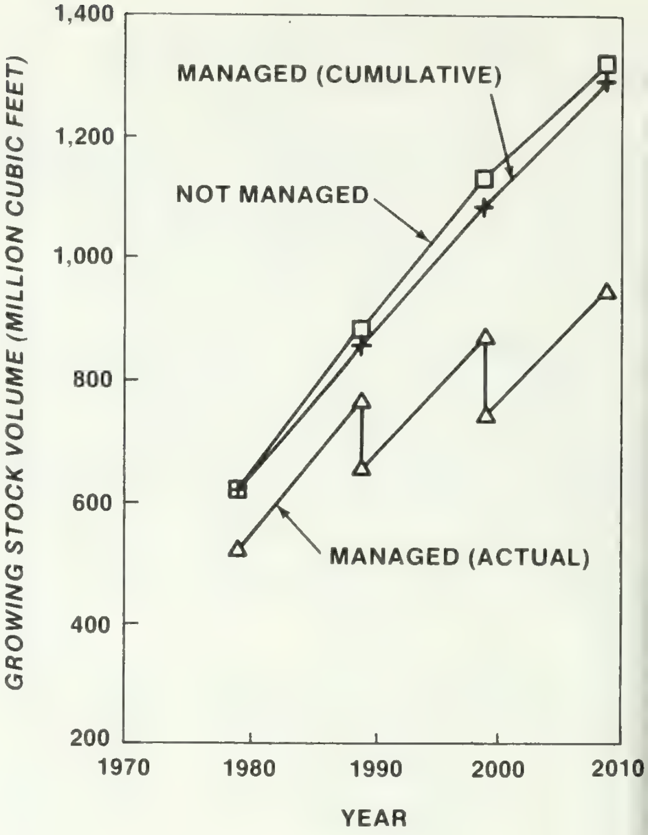

Figure 13.—*Volume of growing stock for Nicolet National Forest, 1979-2009, for all trees with and without management.*

Table 4.—*Summary of acreage and volume/acre of growing stock on the Nicolet National Forest with management applied (timber harvesting)*

			Projected to					
	Updated to 1979		1989		1999		2009	
Cover type	Acres	Merchantable volume	Acres	Merchantable volume	Acres	Merchantable volume	Acres	Merchantable volume
	Thousand	*Cu ft/ac*	*Thousand*	*Cu ft/ac*	*Thousand*	*Cu ft/ac*	*Thousand*	*Cu ft/ac*
Jack pine	3.4	1,265	3.4	1,682	3.4	2,125	3.4	1,892
Red pine	56.2	1,992	56.2	2,897	95.3	2,328	99.2	2,418
White pine	4.9	1,784	4.9	2,416	4.9	3,012	6.4	2,760
Hemlock	21.7	2,310	21.7	2,070	21.7	2,302	21.7	2,518
Balsam fir	43.7	1,207	38.5	1,154	32.7	1,020	26.7	1,354
Black spruce	8.1	1,213	8.1	1,159	8.1	358	8.1	277
N. white-cedar	31.4	1,417	35.1	1,401	35.1	1,615	37.1	1,852
Tamarack	9.9	1,154	9.9	871	9.9	976	9.9	1,262
White spruce	12.5	1,484	16.5	1,900	18.0	1,773	20.5	1,919
N. red oak	6.9	678	6.9	587	6.9	902	6.9	1,356
B. ash-elm-maple	5.0	437	5.0	531	5.0	846	4.6	936
Maple-beech-birch	213.6	1,626	212.8	1,613	217.1	1,728	217.5	1,732
Aspen	93.4	933	97.2	272	55.0	579	46.9	816
Paper birch	16.3	1,700	13.8	1,567	13.8	2,016	17.0	2,283
Other hardwood	0.4	335	0.4	491	0.4	441	0	0
Noncommercial	3.0	590	0	0	3.1	349	4.6	911
Nonstocked	16.1	0	16.1	0	16.1	0	16.1	0
	546.6	1,432	546.6	1,403	546.6	1,600	546.6	1,736

Table 5.—*Summary of acreage and volume/acre of growing stock on the Nicolet National Forest with no management applied (no timber harvesting)*

			Projected to					
	Updated to 1979		1989		1999		2009	
Cover type	Acres	Merchantable volume	Acres	merchantable volume	Acres	Merchantable volume	Acres	Merchantable volume
	Thousand	*Cu ft/ac*	*Thousand*	*Cu ft/ac*	*Thousand*	*Cu ft/ac*	*Thousand*	*Cu ft/ac*
Jack pine	3.4	1,265	3.4	1,619	3.4	1,948	3.4	2,355
Red pine	56.2	1,992	56.2	2,991	56.2	3,936	56.2	4,692
White pine	4.9	1,784	6.4	2,262	6.4	2,863	6.4	3,373
Hemlock	21.7	2,310	21.7	2,335	17.4	2,815	17.4	3,076
Balsam fir	43.7	1,207	32.8	1,324	32.3	1,880	22.7	2,525
Black spruce	8.1	1,213	8.1	1,082	8.1	1,505	8.1	1,927
N. white-cedar	31.4	1,417	31.4	1,569	36.3	1,896	41.5	2,094
Tamarack	9.9	1,154	9.9	918	9.9	964	10.0	1,072
White spruce	12.5	1,484	26.5	1,663	23.9	1,977	25.4	2,268
N. red oak	6.9	678	6.9	944	6.9	1,305	6.9	1,717
B. ash-elm-maple	5.0	437	6.4	576	7.9	839	7.5	1,124
Maple-beech-birch	213.6	1,626	234.9	1,679	241.6	2,119	243.7	2,402
Aspen	93.4	933	59.6	774	54.0	1,164	54.2	1,545
Paper birch	16.3	1,700	16.3	1,813	16.3	2,250	16.3	2,699
Other hardwood	0.4	335	5.4	1,160	5.4	1,327	5.4	1,686
Noncommercial	3.0	590	4.4	625	4.4	848	5.4	753
Nonstocked	16.1	0	16.1	0	16.1	0	16.1	0
	546.6	1,432	546.6	1,615	546.6	2,070	546.6	2,418

be cut, the estimate for mortality volume in the managed projection is approximately half of the estimate for mortality volume in the unmanaged projection. Foresters from the Nicolet National Forest indicated that these mortality estimates were reasonable and well within their expectations.

Comparing the trends in species composition for the 30-year projection with management and without management can indicate the effects of management on the forest (figs. 14 and 15). When management is applied according to the guides within STEMS, hard maple decreases from 18 to 17 percent of the forest's volume. When the forest is allowed to grow with no manmade alterations, hard maple increases to 24 percent of the forest's volume by the year 2009. Quaking aspen drops from 10 to 6 percent with management but only drops to 9 percent without management.

Size distribution of all the trees on the Nicolet National Forest combined (regardless of species) at the beginning and end of the projection period is different with management and without management (fig. 16). With management applied, the 8- and 12-inch diameter classes show almost no change during the projection period. This indicates that the number of trees lost to cutting and mortality in these classes is approximately equal to the growth into these classes.

The managed projection shows more live trees less than 6 inches in diameter in 2009 than the unmanaged projection. This is mostly due to the way regeneration is handled in STEMS. New trees enter the system only after a clearcut or when all the trees on a plot die. These conditions can occur for managed stands but not for unmanaged stands so the small tree component for managed stands is greater.

Table 6.—*Summary of inventory cut and mortality volumes of growing stock trees for the Nicolet National Forest (1979-2009)*

(In million cubic feet)

	Managed					Unmanaged			
Period	Initial	Growth	Cut	Dead	Final	Initial	Growth	Dead	Final
1979-1989	616.6	284.9	96.4	38.5	766.6	616.6	320.3	54.1	882.8
1989-1999	766.6	270.2	117.1	44.8	874.8	882.8	326.3	77.4	1,131.6
1999-2009	874.8	248.0	129.6	44.2	949.0	1,131.6	297.9	108.1	1,321.4
ALL	616.6	803.1	343.1	127.5	949.0	616.6	944.5	239.6	1,321.4

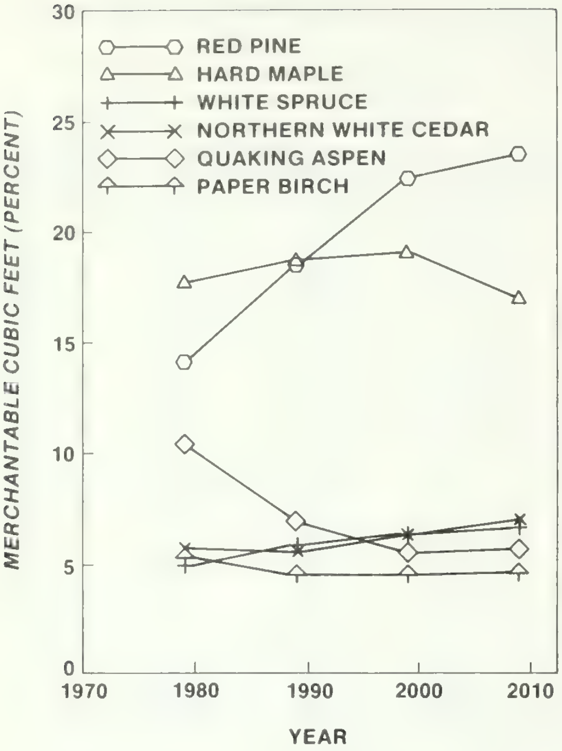

Figure 14.—*Trends in species composition during the 30-year projection period for the Nicolet National Forest when timber management is applied.*

For diameters greater than 6 inches, the unmanaged projection shows more trees in each size class for 2009. This is because thinning removes trees of these sizes. In unmanaged stands, trees are left to grow with only mortality to remove them. The greater number of large diameter trees for the unmanaged condition again points out that the Lake States management guides used in STEMS managed for value rather than tree size.[10]

CONCLUSION

The Stand and Tree Evaluation and Modeling System (STEMS) is an individual-tree, distance-independent growth simulation model developed for Lake States forest conditions. It uses nonlinear regression equations to project potential tree diameter growth, modify that growth for competition effects, and compute probability of mortality and crown-ratio code

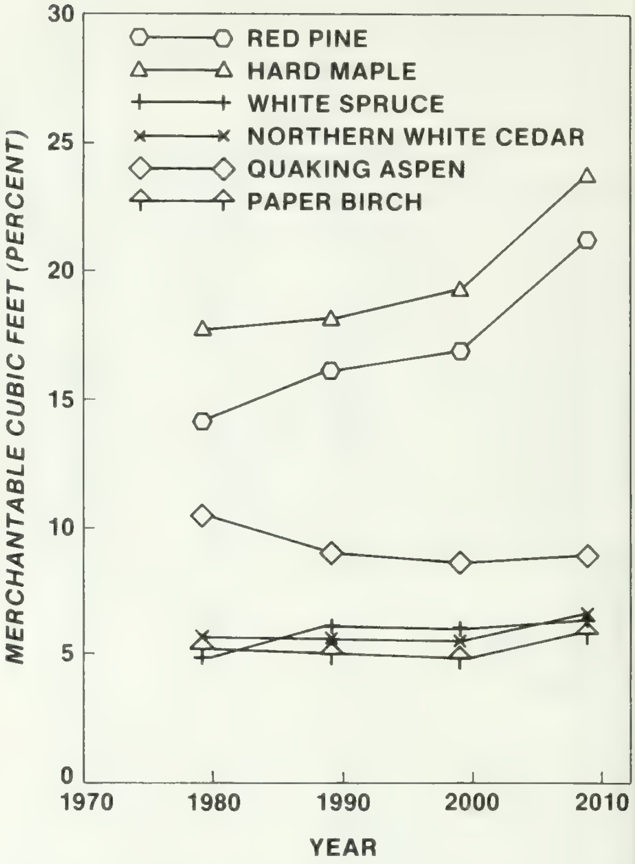

Figure 15.—*Trends in species composition during the 30-year projection period for the Nicolet National Forest when no timber management is applied.*

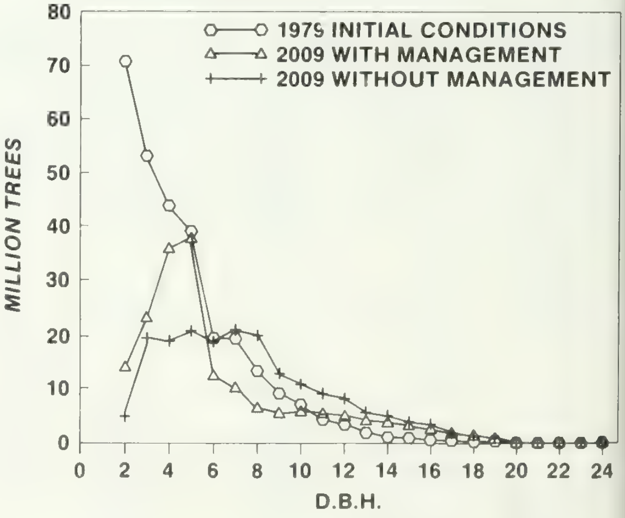

Figure 16.—*Initial and projected size distribution of trees, with and without management.*

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[10] *Personel communication with Allen Lundgren, North Central Forest Experiment Station, September, 1980.*

on a tree-by-tree basis. Management and regeneration subsystems are provided to simulate harvest and regeneration of a stand. STEMS can be used to grow single stands or large areas such as National Forests.

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A description of STEMS—the stand and tree evaluation and modeling system. Gen. Tech. Rep. NC-79. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1982. 18 p.

This paper describes STEMS (Stand and Tree Evaluation and Modeling System), the current computerized Lake States tree growth projection system. It presents the program structure, discusses the growth and mortality components, the management subsystem, and the regeneration subsystem. Some preliminary results of model testing are presented and an application is discussed.

KEY WORDS: Simulation, Lake States species, mortality model, regeneration model, management guides, growth model, projection system, FORTRAN, validation.

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A Net Volume Equation for Michigan's Upper & Lower Peninsulas

Gerhard K. Raile, W. Brad Smith, and Carol A. Weist

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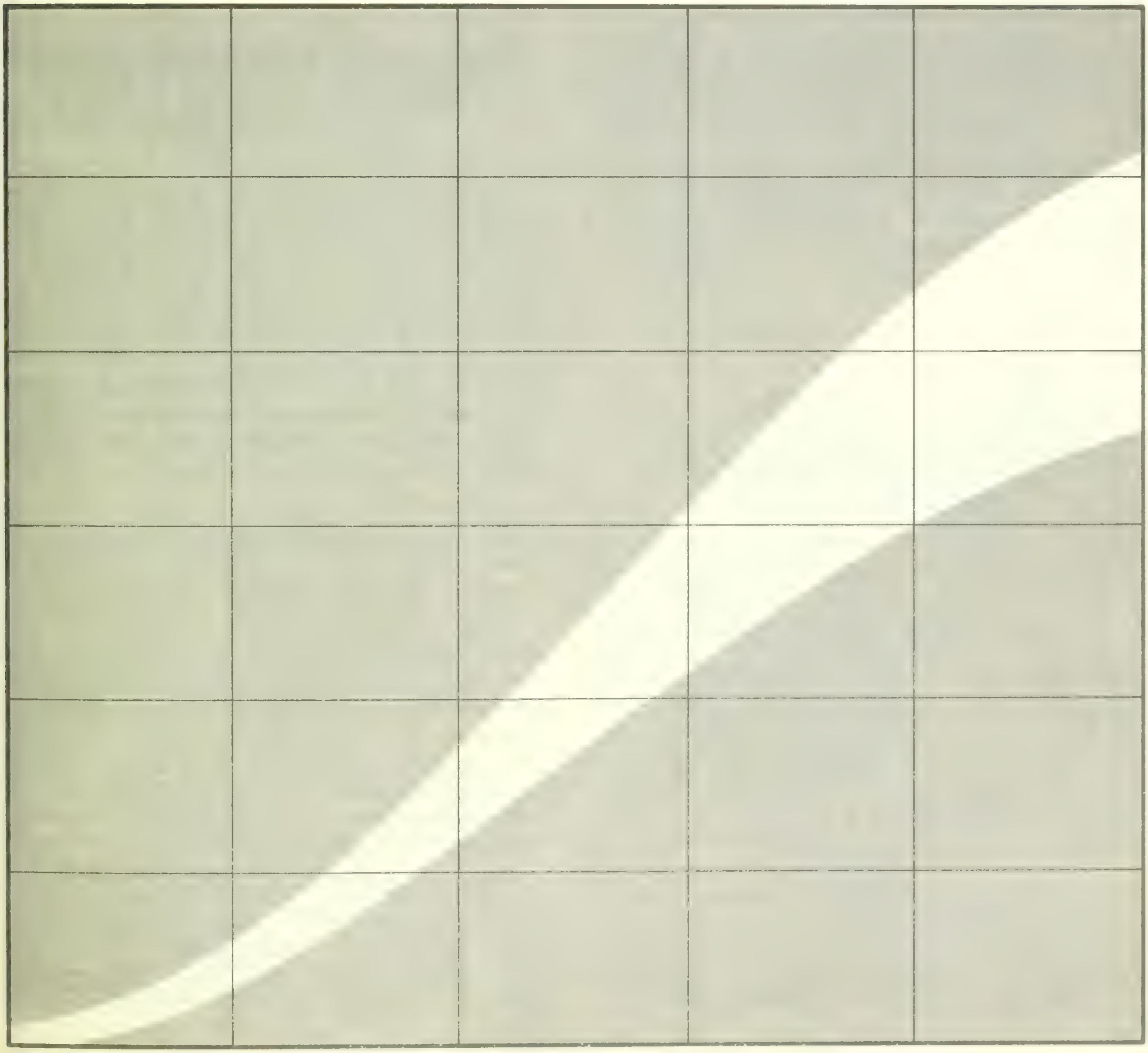


A NET VOLUME EQUATION FOR MICHIGAN'S UPPER AND LOWER PENINSULAS

Gerhard K. Raile, *Mensurationist,*
W. Brad Smith, *Mensurationist,*
and **Carol A. Weist,** *Computer Programmer*

A net merchantable tree volume equation and coefficients were developed for the Upper and Lower Peninsulas as part of the 1981 Michigan Forest Inventory (fig. 1). The equation is suitable for use on digital computers by foresters, land managers, researchers, and others in need of net volume-per-tree estimates over large forest areas. Both board-foot and cubic-foot volume can be estimated for most tree classes.

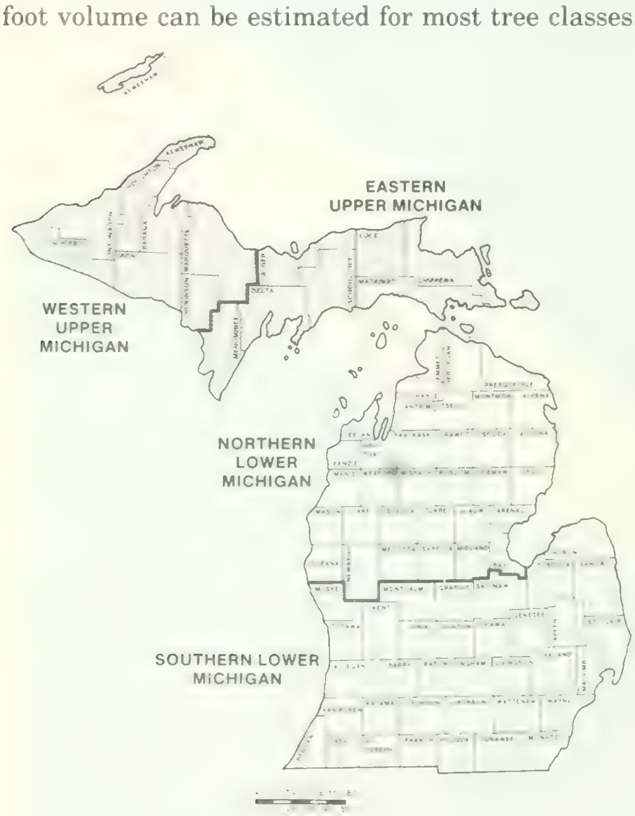


Figure 1.—*Michigan's forest survey units.*

HOW THE EQUATION AND COEFFICIENTS WERE DEVELOPED

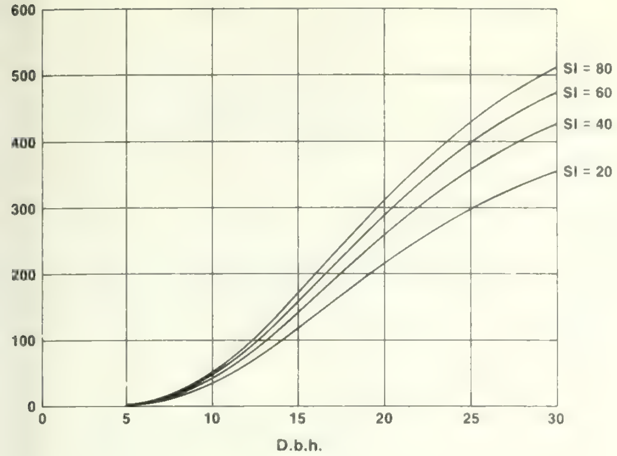
Equations developed by Robert N. Stone (see A pendix) based on Gevorkiantz and Olsen's (195 composite volume tables for the Lake States we used to estimate the cubic-foot volume in each tr Stone's equations compute gross volume in a tr from three measurements: diameter breast heig (d.b.h.), merchantable height, and top diameter o side bark (t.d.o.b.). This estimated volume was th corrected for differences in bark thickness betwe species and the field estimate of cull volume w subtracted to arrive at net volume.

Experience in working with volume-d.b.h. re tions suggests the following equation for this ty of data:

$$V = A \cdot SI^{B} (1-e^{-(C \cdot DBH)})^{D}$$

where the dependent variable V is net volume of t tree, and the independent variables SI and DBH a tree site index and diameter at breast height, spectively. The value of e is the constant base of t natural logarithm (2.71828). A, B, C, and D are t equation coefficients. The upper asympote, $A \cdot SI^{B}$, a function of site index. A general form of this fu tion can be seen graphically in figure 2.

The equation coefficients were developed using fi data collected on 12,361 trees in the Upper Penins and 9,780 trees in the Lower. Data included d.b merchantable height, t.d.o.b., site index, and t class. For sawtimber-size trees, measurements w



igure 2.—*Net board foot volume (International ¼-inch rule) of desirable and acceptable basswood trees by d.b.h. and selected site index levels.*

ken at both the sawtimber and poletimber limits merchantability.[1] Field crews also estimated the lume of board foot and cubic foot cull in each tree JSDA Forest Service 1975).

Equation coefficients were developed for each of ree tree class categories: "desirable and accepta-e," "rough and short-log," and "rotten" (see Ap-endix for definitions). Equation coefficients were so developed for board-foot and cubic-foot volumes. he groupings of species for the equations were de-rmined primarily by the number of observations d the similarity of bole form among species. Spe-es for which no observations were available were signed equations on the basis of bole form. (For ecies and species groups, see Appendix).

A computerized nonlinear regression program was ed to fit the above equation to the tree data. The sulting coefficients and statistics for each regres-n are given in tables 1-7 for the Upper Peninsula d 8-14 for the Lower. Note that the standard error the standard error of the regression.

Because the average site index may be used when site index is unknown, the only other data needed to determine tree volumes using this model are species, d.b.h., and tree class. Net volume per tree is highly variable, so these equations should be applied to an adequate sample over a large forest area.

HOW TO USE THE EQUATION

1. Select the appropriate species group and coefficients from tables 1-14.
2. Substitute these coefficients in the above equation.
3. Solve the equation to obtain net volume.

For example, to compute the board foot volume of a 15-inch acceptable basswood tree with a site index of 60 in the Lower Peninsula, we would first obtain the coefficients for basswood from table 11. Substituting into the general net volume equation:

$$V = A \cdot SI^{B} (1-e^{-C \cdot DBH})^{D}$$

$$V = (2076.0)(60)^{(.17993)} (1-e^{-0.02575(15.0)})^{2.921}$$

$$V = 156 \text{ board feet}$$

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[1] *The poletimber merchantability limits include trees 0 inches d.b.h. and over, from a 1-foot stump to a inimum of 4.0-inch t.d.o.b. or to the point where the ntral stem breaks into limbs. Dimensions for sawnber are 9.0-inch d.b.h. to a minimum 7-inch t.d.o.b. r softwoods and 11.0-inch d.b.h. to a minimum 9.0-ch t.d.o.b. for hardwoods or to the point where the ntral stem breaks into limbs.*

Table 1.--Net cubic foot volume regression coefficients for desirable and acceptable trees, Upper Peninsula, Michigan, 1981

Species group	Coefficient				Site index		D.b.h.		Observations	Standard error
	A	B	C	D	Range	Average	Range	Average	Number	Cubic feet
Jack pine	4.325×10^{1}	0.24942	0.06338	3.398	25-82	63	5-18	9	163	2.0
Red pine	2.083×10^{2}	.10151	.04348	3.281	43-80	62	5-23	12	104	4.1
White pine	7.116×10^{6}	.24602	.00052	2.780	30-82	56	5-32	16	287	15.7
White spruce	7.942×10^{2}	.08698	.02469	3.034	20-82	53	5-26	11	333	4.6
Black spruce	2.398×10^{7}	.14839	.00036	2.694	21-92	46	5-21	7	374	1.3
Balsam fir	5.907×10^{6}	.21264	.00056	2.716	19-92	54	5-28	8	898	1.8
Hemlock	7.702×10^{6}	.30587	.00027	2.564	43-95	71	5-34	14	516	7.3
Tamarack	4.351×10^{1}	0	.16016	5.623	27-63	48	5-16	8	68	1.7
N. white-cedar	8.297×10^{5}	.05522	.00067	2.339	10-58	30	5-25	9	953	2.7
Red oak	2.260×10^{2}	.06018	.04078	3.068	43-87	63	5-27	12	161	3.6
Basswood	2.208×10^{2}	.12196	.03593	2.944	48-91	67	5-25	11	298	3.8
Beech	1.156×10^{2}	.23099	.03388	2.617	46-97	67	5-22	12	95	4.7
Yellow birch	4.118×10^{6}	.29140	.00021	2.301	30-83	61	5-36	13	522	6.2
Hard maple	5.004×10^{2}	.00742	.02825	2.758	20-85	63	5-28	11	2,272	4.7
Soft maple	8.410×10^{1}	.13855	.05764	3.184	12-90	61	5-26	10	1,318	3.3
Elm	1.398×10^{2}	.43871	.01912	2.539	42-87	65	5-27	11	211	3.3
Ash	2.692×10^{4}	.14046	.00313	2.428	33-90	59	5-25	9	226	2.8
Cottonwood-balsam poplar	7.257×10^{6}	1.01628	.00018	2.837	22-96	67	5-33	12	165	7.2
Aspen	1.577×10^{2}	.21361	.03154	2.717	32-96	71	5-25	10	994	3.2
Paper birch	7.256×10^{3}	.10993	.00363	2.093	19-86	59	5-25	10	520	2.4
Other hardwoods	1.444×10^{1}	.33869	.11817	4.489	43-87	62	5-19	9	83	2.0

Table 2.--Net cubic foot volume regression coefficients for rough and short-log trees, Upper Peninsula, Michigan, 1981

Species group	Coefficient				Site index		D.b.h.		Observations	Standard error
	A	B	C	D	Range	Average	Range	Average	Number	Cubic feet
Softwoods	1.218×10^{7}	0.31779	0.00017	2.472	10-88	45	5-30	10	236	4.3
Beech	2.133×10^{2}	0	.04384	3.161	53-92	68	6-24	14	19	10.8
Yellow birch	5.424×10^{1}	.71702	.01995	3.021	30-83	60	5-33	14	84	11.6
Hard maple	2.914×10^{6}	0	.00031	2.207	39-85	62	5-28	11	212	4.2
Soft maple	4.162×10^{1}	.20572	.05977	3.073	31-84	60	5-25	11	121	4.4
Aspen	1.492×10^{5}	.45481	.00034	2.079	45-96	69	5-20	11	61	3.6
Paper birch	2.697×10^{4}	0	.00161	1.959	33-76	56	5-21	10	26	2.9
Other hardwoods	7.614×10^{3}	.44924	.10296	3.961	45-78	61	6-14	9	36	1.6
Noncommercial species	4.543×10^{5}	.51085	.00035	2.308	45-90	66	5-15	8	58	1.9

Table 3.--Net cubic foot volume regression coefficients for rotten trees, Upper Peninsula, Michigan, 1981

Species group	Coefficient				Site index		D.b.h.		Observations	Standard error
	A	B	C	D	Range	Average	Range	Average		
									Number	Cubic feet
Softwoods	1.835×10^6	0.15210	0.00133	3.271	10-98	38	5-40	12	248	7.8
Beech	1.731×10^4	1.29100	.00022	2.149	53-75	61	6-22	14	39	5.9
Yellow birch	5.915×10^1	0	.09740	5.555	40-83	60	5-37	17	124	13.8
Hard maple	1.058×10^6	.73128	.00016	2.367	43-85	62	5-30	13	125	6.6
Soft maple	3.962×10^4	1.42808	.00012	2.180	36-82	60	5-27	12	104	6.2
Aspen	9.412×10^5	.13671	.00062	2.484	35-96	68	5-24	12	143	4.8
Paper birch	1.433×10^1	0	.28871	10.861	19-86	57	5-26	12	31	4.0
Other hardwoods	1.000×10^3	.10882	.02847	4.891	14-94	60	5-33	11	53	6.2

Table 4.--Net board foot[1] volume regression coefficients for desirable and acceptable trees, Upper Peninsula, Michigan, 1981

Species group	Coefficient				Site index		D.b.h.		Observations	Standard error
	A	B	C	D	Range	Average	Range	Average		
									Number	Cubic feet
Jack pine	1.686×10^2	0.39511	0.05124	3.196	25-72	66	9-18	12	75	19.2
Red pine	2.969×10^3	.25519	.01790	2.761	44-77	61	9-23	14	77	32.2
White pine	3.628×10^7	.14236	.00083	2.973	30-82	56	9-35	17	260	98.1
White spruce	3.525×10^4	0	.01109	2.866	20-82	54	9-26	13	215	36.0
Black spruce	2.894×10^7	.06307	.00140	3.165	21-92	49	9-21	11	45	18.7
Balsam fir	2.798×10^4	.33410	.00969	3.261	25-92	55	9-28	11	221	21.3
Hemlock	2.587×10^6	.05437	.00139	2.636	43-95	72	9-34	15	442	52.6
Tamarack	6.298×10^1	.22695	.32850	26.891	27-59	52	9-16	11	17	12.1
N. white-cedar	5.756×10^6	0	.00079	2.463	10-58	32	9-25	13	375	31.2
Red oak	1.007×10^3	0	.06887	4.382	43-87	64	11-26	15	95	38.4
Basswood	2.014×10^2	.26549	.11156	6.420	48-85	66	11-25	15	114	47.4
Beech	3.153×10^2	.17511	.08716	4.435	46-97	67	11-22	14	53	47.9
Yellow birch	4.005×10^2	.31603	.04587	3.418	36-83	60	11-36	16	303	63.3
Hard maple	7.117×10^2	0	.09952	5.866	39-85	63	11-28	15	905	56.4
Soft maple	1.203×10^2	.27194	.17342	11.676	38-84	61	11-26	14	431	90.9
Elm	1.211×10^6	.57652	.00013	1.834	42-87	64	11-27	15	95	58.0
Ash	1.093×10^7	.02244	.00082	2.564	33-90	58	11-25	14	64	37.6
Cottonwood-balsam poplar	1.594×10^7	.75718	.00029	2.740	41-96	71	11-33	16	88	51.9
Aspen	3.933×10^2	.19532	.06404	3.681	42-96	73	11-25	14	381	38.4
Paper birch	9.104×10^6	0	.00017	1.882	23-86	58	11-25	14	144	28.8
Other hardwoods	8.070×10^3	.63809	.00040	1.346	48-87	65	11-19	13	20	19.3

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[1] International 1/4-inch rule.

Table 5.--Net board foot[1] volume regression coefficients for rough and short-log trees, Upper Peninsula, Michigan, 1981

	Coefficient				Site index		D.b.h.			
Species group	A	B	C	D	Range	Average	Range	Average	Observations	Standard error
									Number	Cubic feet
N. white-cedar	1.910×10^3	0	.00138	1.014	14-45	30	9-20	12	37	15.4
Softwoods[2]	1.012×10^7	0	0.00016	2.009	35-87	65	9-29	13	41	17.8
Yellow birch	4.006×10^4	0	.00204	1.757	46-80	62	11-33	18	37	155.8
Hard maple	9.304×10^1	0.02006	.23417	16.842	39-85	64	11-21	15	63	28.9
Soft maple	3.015×10^2	0	.06176	3.223	31-74	57	11-26	15	42	31.8
Aspen	1.357×10^4	.77549	.00012	1.419	49-96	71	11-20	14	26	31.8
Other hardwoods	2.236×10^2	.43694	.03429	3.519	33-92	65	11-24	15	40	31.2

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[1] International 1/4-inch rule.
[2] Softwoods other than white-cedar.

Table 6.--Net cubic foot saw-log volume regression coefficients for desirable and acceptable trees, Upper Peninsula, Michigan, 1981

	Coefficient				Site index		D.b.h.			
Species group	A	B	C	D	Range	Average	Range	Average	Observations	Standard error
									Number	Cubic feet
Jack pine	8.947×10^0	0.53396	0.08549	4.216	25-72	66	9-18	12	75	2.7
Red pine	1.727×10^2	.13296	.04191	3.166	44-77	61	9-23	14	77	4.7
White pine	2.797×10^7	.15545	.00034	2.776	30-82	56	9-35	18	260	14.1
White spruce	7.649×10^2	.02644	.02773	3.168	20-82	54	9-26	13	215	5.6
Black spruce	1.321×10^7	.02868	.00090	3.047	21-92	49	9-20	11	45	3.1
Balsam fir	3.496×10^2	.39522	.02444	3.503	25-92	55	9-28	11	221	3.2
Hemlock	1.374×10^4	.09324	.00506	2.643	43-95	72	9-34	15	442	7.2
Tamarack	1.185×10^1	.22306	.29331	20.224	27-59	52	9-16	11	17	2.0
N. white-cedar	3.293×10^2	.04549	.03184	3.132	10-58	32	9-24	13	375	4.3
Red oak	9.210×10^1	0	.11298	6.721	43-87	64	11-26	15	95	4.5
Basswood	3.254×10^1	.23508	.13247	8.230	48-85	66	11-25	15	114	6.3
Beech	5.942×10^1	.20844	.06226	3.507	46-97	67	11-22	14	53	7.1
Yellow birch	2.327×10^2	.18111	.02860	2.971	36-83	60	11-36	16	303	8.3
Hard maple	1.157×10^2	0	.09714	5.752	39-85	63	11-28	15	905	7.6
Soft maple	3.425×10^1	.18168	.14025	8.552	38-84	61	11-26	14	431	9.5
Elm	3.158×10^5	.63848	.00010	1.886	42-87	64	11-27	15	95	9.4
Ash	2.361×10^6	.08194	.00049	2.400	33-90	58	11-25	14	64	5.7
Cottonwood-balsam poplar	9.227×10^6	.62755	.00017	2.606	41-96	71	11-33	16	88	7.1
Aspen	3.552×10^1	.25513	.08955	4.727	42-96	73	11-25	14	381	5.3
Other hardwoods	2.327×10^2	.18111	.02860	2.971	36-83	60	11-36	16	303	8.3

Table 7.--Net cubic foot saw-log volume regression coefficients for rough and short-log trees, Upper Peninsula, Michigan, 1981

Species group	Coefficient				Site index		D.b.h.		Observations	Standard error
	A	B	C	D	Range	Average	Range	Average	Number	Cubic feet
Softwoods	3.985×10^{4}	0.07070	0.00175	2.318	14-45	30	9-20	12	37	1.9
Yellow birch	8.576×10^{5}	.00850	.00048	2.216	46-80	62	11-33	18	37	16.8
Hard maple	2.639×10^{1}	.17348	.15635	12.624	39-85	64	11-21	15	63	6.3
Soft maple	5.080×10^{1}	0	.13449	9.180	31-74	57	11-26	15	42	5.0
Aspen	2.334×10^{0}	1.20985	.01793	2.329	49-96	71	11-20	14	26	4.0
Other hardwoods	1.985×10^{5}	0	.00182	2.685	33-92	65	11-24	15	40	4.2

Table 8.--Net cubic foot volume regression coefficients for desirable and acceptable trees, Lower Peninsula, Michigan, 1981

Species group	Coefficient				Site index		D.b.h.		Observations	Standard error
	A	B	C	D	Range	Average	Range	Average	Number	Cubic feet
Jack pine	4.325×10^{1}	0.24942	0.06338	3.398	40-82	58	5-17	8	206	1.7
Red pine	1.143×10^{2}	0	.07601	3.928	41-82	66	5-22	10	292	2.3
White pine	7.519×10^{6}	.15234	.00054	2.726	34-86	57	5-31	15	195	16.3
White spruce	3.559×10^{2}	0	.04443	3.352	25-68	48	5-19	10	111	4.6
Black spruce-tamarack	1.296×10^{7}	.19981	.00043	2.700	22-87	45	5-14	7	160	1.3
Balsam fir	2.455×10^{7}	0	.00059	2.843	25-77	54	5-18	7	343	1.3
Hemlock	6.908×10^{6}	.57395	.00016	2.493	48-94	69	5-27	13	218	6.7
N. white-cedar	3.396×10^{5}	0	.00100	2.305	15-58	32	5-23	8	975	1.9
Other softwoods	1.143×10^{2}	0	.07601	3.928	56-75	64	5-12	7	34	1.0
White oak	5.598×10^{5}	0	.00069	2.200	30-84	64	5-42	13	312	6.3
Red oak	2.835×10^{2}	.04236	.04104	3.205	40-99	65	5-38	12	739	5.0
Hickory	6.638×10^{1}	.05243	.10201	4.680	50-83	66	5-20	11	50	2.2
Basswood	2.458×10^{5}	.34244	.00072	2.323	46-95	70	5-29	11	307	4.5
Beech	6.180×10^{2}	.12032	.01730	2.445	46-97	70	5-25	12	225	5.6
Yellow birch	4.095×10^{2}	.22434	.01586	2.388	39-80	61	6-26	13	105	5.2
Hard maple	2.411×10^{2}	.20816	.02332	2.492	34-98	68	5-31	10	1,136	3.9
Soft maple	3.455×10^{1}	.50730	.04165	3.056	27-95	66	5-50	11	891	5.0
Elm	2.574×10^{2}	.05352	.03621	2.958	41-92	68	5-26	10	121	2.1
Ash	3.267×10^{2}	.17118	.02287	2.617	22-97	68	5-38	10	366	2.6
Cottonwood	4.447×10^{3}	.28134	.00686	2.715	63-97	78	7-36	16	52	9.5
Balsam poplar	8.6[illegible] x 10^{2}	.01915	.02039	2.701	37-94	66	5-22	11	144	3.6
Aspen	3.140×10^{1}	.40269	.05728	3.339	39-99	72	5-27	10	1,039	2.9
Paper birch	5.045×10^{1}	.10011	.08744	3.591	19-90	62	5-18	9	363	2.0
Black cherry	1.155×10^{1}	.48724	.08182	3.509	39-93	71	5-33	11	105	4.5
Other hardwoods	9.051×10^{5}	.05103	.00072	2.353	48-96	79	5-41	15	63	15.6

Table 9.--Net cubic foot volume regression coefficients for rough and short-log trees, Lower Peninsula, Michigan, 1981

Species group	Coefficient				Site index		D.b.h.		Observations	Standard error
	A	B	C	D	Range	Average	Range	Average	Number	Cubic feet
N. white-cedar	2.407×10^7	0	0.00016	2.352	17-58	30	5-20	9	107	2.3
Softwoods[1]	1.218×10^7	.29455	.00006	2.165	33-84	62	5-20	8	97	2.5
Hardwoods	1.749×10^3	.44290	.00403	2.238	31-99	66	5-43	12	436	7.9
Noncommercial species	5.725×10^2	.55858	.00457	2.150	35-99	69	5-15	8	61	2.3

[1] Softwoods other than white-cedar.

Table 10.--Net cubic foot volume regression coefficients for rotten trees, Lower Peninsula, Michigan, 1981

Species group	Coefficient				Site index		D.b.h.		Observations	Standard error
	A	B	C	D	Range	Average	Range	Average	Number	Cubic feet
N. white-cedar	1.835×10^6	0.10408	0.00008	1.870	18-58	32	5-30	10	152	2.8
Softwoods[1]	1.218×10^7	.29455	.00006	2.165	34-98	61	5-40	14	35	36.6
Hardwoods	6.170×10^1	.35651	.02913	2.816	19-99	65	5-47	13	340	8.4

[1] Softwoods other than white-cedar.

Table 11.--Net board foot[1] volume regression coefficients for desirable and acceptable trees, Lower Peninsula, Michigan, 1981

Species group	Coefficient				Site index		D.b.h.		Observations	Standard error
	A	B	C	D	Range	Average	Range	Average	Number	Cubic feet
Jack pine	2.507×10^2	0	0.14611	6.309	40-75	59	9-17	11	57	13.2
Red pine	3.449×10^2	0	.14728	7.536	41-82	62	9-22	13	132	22.9
White pine	7.435×10^6	.18431	.00133	2.960	34-86	57	10-31	17	158	116.1
White spruce	1.232×10^4	0	.01818	3.025	26-68	47	9-19	13	63	34.4
Black spruce-tamarack	1.137×10^6	.46220	.00342	3.471	34-87	49	9-14	11	27	10.0
Balsam fir	1.212×10^3	0	.08642	6.011	25-69	53	9-18	11	48	18.7
Hemlock	7.805×10^2	.37007	.03753	3.990	48-94	68	9-27	15	158	55.8
N. white-cedar	5.756×10^6	0	.00075	2.437	17-58	33	9-23	12	271	26.4
White oak	1.901×10^3	.13500	.02718	2.949	45-84	67	11-42	18	166	59.4
Red oak	1.110×10^3	0	.07531	5.081	40-99	67	11-38	16	372	49.9
Hickory	3.183×10^2	0	.21096	14.474	58-73	65	11-20	15	25	24.9
Basswood	2.076×10^3	.17993	.02575	2.921	46-95	71	11-29	15	134	42.5
Beech	4.626×10^2	0	.14504	8.794	46-97	69	11-25	15	115	53.7
Yellow birch	7.302×10^2	0	.08150	4.721	47-80	62	11-26	15	67	46.1
Hard maple	6.809×10^2	.07082	.06900	4.079	46-98	69	11-31	15	405	50.6
Soft maple	2.571×10^2	.43970	.03910	2.950	31-95	69	11-50	16	348	105.3
Elm	1.513×10^2	.37200	.07717	4.435	41-92	67	11-26	14	36	29.2
Ash	1.073×10^3	.05396	.05372	3.748	42-97	74	11-38	15	106	34.1
Cottonwood	9.202×10^4	0	.00581	2.572	63-97	78	12-36	18	42	75.1
Balsam poplar	1.970×10^6	.17284	.00017	1.708	45-94	67	11-22	15	64	81.0
Aspen	1.997×10^2	.21261	.12888	7.269	43-99	74	11-27	14	373	35.5
Paper birch	9.296×10^6	0	.00024	1.995	23-81	64	11-18	13	71	27.3
Black cherry	2.557×10^1	.46049	.44366	148.962	39-93	76	11-33	15	36	44.1
Other hardwoods	3.651×10^6	.01140	.00106	2.475	48-96	80	11-41	18	42	120.4

[1] International 1/4-inch rule.

Table 12.--Net board foot[1] volume regression coefficients for rough and short-log trees, Lower Peninsula, Michigan, 1981

Species group	Coefficient				Site index		D.b.h.		Observations	Standard error
	A	B	C	D	Range	Average	Range	Average	Number	Cubic feet
N. white-cedar	6.854×10^2	0.21868	0.00182	1.025	19-48	30	9-20	12	39	12.2
Softwoods[2]	6.854×10^2	.21868	.00182	1.025	35-84	59	9-20	12	25	22.6
Hardwoods	6.622×10^4	0	.00244	2.132	31-99	68	11-40	17	132	66.0

[1] International 1/4-inch rule.
[2] Softwoods other than white-cedar.

Table 13.--Net cubic foot saw-log volume regression coefficients for desirable and acceptable trees, Lower Peninsula, Michigan, 1981

Species group	Coefficient				Site index		D.b.h.		Observations	Standard error
	A	B	C	D	Range	Average	Range	Average	Number	Cubic feet
Jack pine	7.341×10^1	0	0.11096	5.616	40-75	59	9-17	11	57	2.5
Red pine	6.309×10^1	0	.12942	6.202	41-82	62	9-22	13	132	3.1
White pine	1.619×10^5	.14896	.00231	2.786	34-86	57	10-31	17	158	16.2
White spruce	2.260×10^2	0	.06044	4.051	26-68	47	9-19	13	63	5.6
Black spruce-tamarack	2.006×10^4	.48355	.00726	3.611	34-87	49	9-14	11	27	2.1
Balsam fir	1.883×10^2	0	.09892	6.826	25-69	53	9-18	11	48	2.6
Hemlock	7.393×10^1	.43473	.03939	3.775	48-94	68	9-27	15	158	7.3
N. white-cedar	4.333×10^3	0	.00821	2.534	17-58	33	9-23	12	271	3.4
White oak	5.830×10^2	0	.02283	2.673	45-84	67	11-42	18	166	8.2
Red oak	1.700×10^2	0	.07359	4.831	40-99	67	11-38	16	372	7.4
Hickory	4.403×10^1	0	.27354	28.212	58-73	65	11-20	15	25	4.1
Basswood	8.881×10^4	.30682	.00108	2.287	46-95	71	11-29	15	134	6.3
Beech	9.970×10^1	0	.09524	5.123	46-97	69	11-25	15	115	7.8
Yellow birch	1.252×10^2	0	.07606	4.522	47-80	62	11-26	15	67	6.2
Hard maple	1.042×10^2	.07535	.06888	4.024	46-98	69	11-31	15	405	6.8
Soft maple	5.000×10^1	.41519	.03792	2.982	31-95	69	11-50	16	348	11.3
Elm	5.794×10^5	.25782	.00031	2.111	41-92	67	11-26	14	36	4.4
Ash	1.925×10^2	.18900	.03068	2.935	42-97	74	11-38	15	106	4.9
Cottonwood	1.841×10^7	0	.00021	2.347	63-97	78	12-36	18	42	10.1
Balsam poplar	4.189×10^6	.07181	.00013	1.982	45-94	67	11-22	15	64	13.1
Aspen	1.882×10^1	.32999	.13786	8.007	43-99	74	11-27	14	373	4.8
Paper birch	3.256×10^1	0	.21722	12.303	23-81	64	11-18	13	71	4.0
Black cherry	2.950×10^0	.64209	.17603	9.090	39-93	76	11-33	15	36	6.7
Other hardwoods	7.655×10^5	.06225	.00065	2.308	48-96	80	11-41	18	42	16.2

Table 14.--Net cubic foot saw-log volume regression coefficients for rough and short-log trees, Lower Peninsula, Michigan, 1981

Species group	Coefficient				Site index		D.b.h.		Observations	Standard error
	A	B	C	D	Range	Average	Range	Average	Number	Cubic feet
N. white-cedar	1.597×10^7	0	0.00028	2.563	19-48	30	9-20	12	39	2.0
Softwoods[1]	1.597×10^7	0	.00028	2.563	35-84	59	9-20	12	25	5.2
Hardwoods	8.525×10^1	.34516	.02714	3.028	31-99	68	11-40	17	132	10.2

[1] Softwoods other than white-cedar.

CORRECTION

A printing error was made in our General Technical Report NC-80, A NET VOLUME EQUATION FOR MICHIGAN'S UPPER & LOWER PENINSULAS, which you received in our previous mailing. On page 11, near the bottom of the "Volume Equations" section, the equation should read as follows:

$$BV = 17.7488 + 7.3846 \cdot CV - 2.3523 \cdot D - 0.89945 \cdot H + 2.0726 \cdot T$$

APPENDIX

VOLUME EQUATIONS

Stone's cubic foot volume equation uses the following dependent variables: diameter at breast height (D), merchantable height (H), and diameter outside bark at merchantable height (T) to estimate cubic foot volume (CV).

$$CV = (3.0086 \times 10^{-3} + S1 + S2 + S3 + S4 + S5 + S6 + S7 + S8) \cdot 79.0$$

where

$S1 = (2.0355 \times 10^{-3})D$

$S2 = (-3.0018 \times 10^{-3})T$

$S3 = (6.2381 \times 10^{-5})D^2$

$S4 = (2.5705 \times 10^{-5})D^2 \cdot H$

$S5 = (-7.0090 \times 10^{-6})H^2$

$S6 = (3.6708 \times 10^{-5})H \cdot T^2$

$S7 = (8.1400 \times 10^{-10})D^2 \cdot H^3$

$S8 = (-1.90000 \times 10^{-9})D^2 \cdot H^2 \cdot T$

Stone's board foot volume equation as modified by Hahn (1975, 1976) is as follows:

$$BV = 17.7488 + 7.38465 \cdot 4CV - 2.35235 \cdot 4D - 0.899455 \cdot 4H + 2.07265 \cdot 4T$$

where

BV = board foot volume (International ¼-inch rule).

SPECIES GROUPS AND SPECIES FOR MICHIGAN TREES

Species group	Scientific names of included species
SOFTWOODS	
Jack pine	*Pinus banksiana*
Red pine	*Pinus resinosa*
White pine	*Pinus strobus*
White spruce	*Picea glauca*
Black spruce	*Picea mariana*
Balsam fir	*Abies balsamea* var. *balsamea*
Hemlock	*Tsuga canadensis*
Tamarack	*Larix laricina*
Northern white-cedar	*Thuja occidentalis*
Other softwoods	*Pinus sylvestris*
	Pinus nigra
	Juniperus virginia
	Larix decidua
	Picea abies
	Pseudotsuga menziesii
HARDWOODS	
White oak	*Quercus alba*
	Quercus bicolor
	Quercus macrocarpa
	Quercus muehlenbergii
Red oak	*Quercus rubra*
	Quercus velutina
	Quercus palistris
	Quercus ellipsoidalis
Hickory	*Carya cordiformis*
	Carya ovata
	Carya glabra
Basswood	*Tilia americana*
Beech	*Fagus grandifolia*
Yellow birch	*Betula alleghaniensis*
Hard maple	*Acer nigrum*
	Acer saccharum
Soft maple	*Acer rubrum* var. *rubrum*
	Acer saccharum
Elm	*Ulmus americana*
	Ulmus rubra
	Ulmus thomasii
Ash	*Fraxinus americana*
	Fraxinus nigra
	Fraxinus pennsylvanica
Cottonwood	*Populus deltoides*
Balsam poplar	*Populus balsamifera*
Paper birch	*Betula papyrifera* var. *papyrifera*
Aspen	*Populus grandidentata*
	Populus tremuloides
Black cherry	*Prunus serotina*
Other hardwoods	*Acer negundo*
	Betula nigra
	Celtis occidentalis
	Juglans cinerea
	Juglans nigra
	Salix nigra
	Liriodendron tulipifera
Noncommercial species	

METRIC EQUIVALENTS

1,000 board feet (International ¼-inch log rule) = 3.48 cubic meters.

Breast height = 1.37 meters above the ground.

1 cubic foot = 0.0283 cubic meter.

1 foot = 30.48 centimeters or 0.3048 meter.

1 inch = 25.4 millimeters or 2.54 centimeters or 0.0254 meter.

DEFINITION OF TERMS (USDA Forest Service 1975)

Desirable trees.—Live trees that have no serious defects that limit present or prospective use and that have relatively high vigor and have no visible signs of pathogens that may result in death or serious deterioration before rotation age. They would be favored by forest managers in silvicultural operations.

Acceptable trees.—Live trees having no serious defects that limit present or prospective use but that have pathogens or damage that may affect quality.

Rough trees.—Live trees that do not contain at least one merchantable 12-foot log, now or prospectively, because of roughness, poor form, or noncommercial species.

Rotten trees.—"Rough" trees in which more than 50 percent of the cull volume is rotten.

Short-log trees.—Live sawtimber-size trees that contain at least one merchantable 8- to 11-foot saw log but not a 12-foot saw log, now or prospectively.

Raile, Gerhard K.; Smith, W. Brad; Weist, Carol A.
A net volume equation for A net volume equation for Michigan's Upper and Lower Peninsulas. Gen. Tech. Rep. NC-80. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1982. 12 p.

Describes a volume equation for Michigan's Upper and Lower Peninsulas developed as part of the 1981 Michigan Forest Inventory. Equation coefficients are presented by species groupings for both cubic-foot and board-foot volumes for three tree categories.

KEY WORDS: Inventory, computer, growing stock, cull, cubic foot, board foot.

North Central Forest Experiment Station
Forest Service—U.S. Department of Agriculture
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United States Department of Agriculture

Forest Service

North Central Forest Experiment Station

General Technical Report **NC-81**

Methods of Rapid, Early Selection of Poplar Clones For Maximum Yield Potential:

A Manual of Procedures

GOVERNMENT
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North Central Forest Experiment Station
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1983

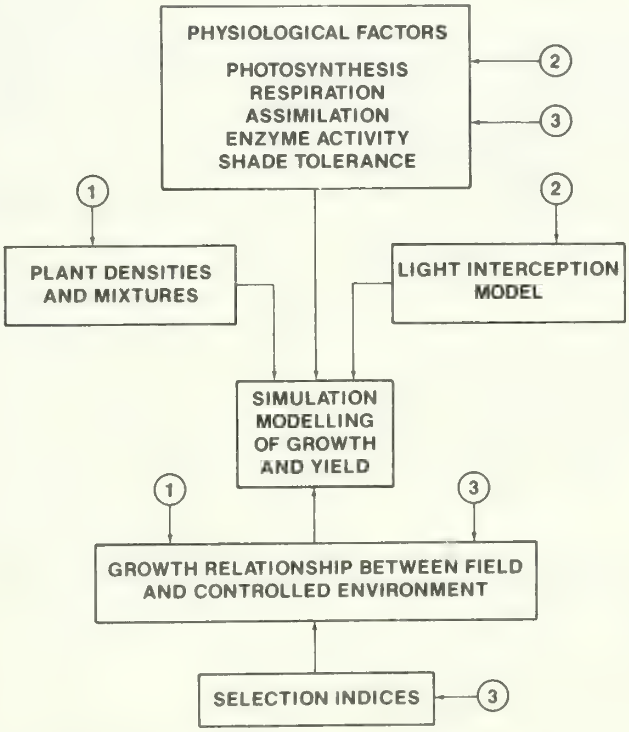
FOREWORD

Since 1920, large increases in productivity have been achieved with agricultural plants such as corn, but no comparable increases have been attained with woody plants. Thus, in the last 10 years, increased attention has been focused on the need for more intensive silvicultural practices to increase fiber production per unit area of land.

Populus clones are currently being examined for use in intensive silvicultural systems because of their rapid growth, ease of propagation, and high utility for a variety of wood-fiber products (Schreiner 1959, Cram 1960, Larson and Gordon 1969, Dawson and Hutchinson 1973). Because more *Populus* species and variants are available than can be reasonably field tested, a rapid technique for selecting superior clones must be devised. A desirable technique must be simple and fast, in contrast to field-growth studies that might take from 3 to 20 years and would occupy large areas. If controlled-environment growth studies and physiological indicators can be used to select genotypes capable of rapid growth, field trials can be smaller, with attendant savings in time, effort, and money.

The chances of successful early selection of poplar clones are enhanced by the genetic constancy of clonal material, by the great amount of knowledge about poplars and their culture already accumulated, and by the well-defined cultural conditions and relatively short rotations used in the intensive silviculture systems now emerging (e.g., Larson and Gordon 1969). Intensive culture and short rotations, particularly, improve the chances of successful selection because environmental variation and time are both small.

For maximum efficiency, early selection systems must be integrated with overall yield improvement efforts. Selection systems should also be capable of continuous improvement while in use. The early selection methods described here are to be used in the yield improvement model illustrated below.



DATA INPUTS
1 = FIELD
2 = GREENHOUSE
3 = GROWTH CHAMBER

Described herein are methods of propagation, culture in controlled environments, and construction and testing of selection indices for poplar clones. The next obvious improvement is the use of physiological, as well as growth, measurements to improve the predictive capability of selection indices. Such possibilities for poplars have been examined (Gordon and Promnitz 1976) but will not be discussed here.

The primary objective of this manual is to describe, for researchers in intensive poplar culture, ways of using controlled environments to select clones that have a high probability of rapid growth in the field. Our system has some limitations: We have no guidelines yet for early selection for insect and disease resistance, nor for resistance to extreme environmental stress (late frost, drought). We **can** identify clones with high growth potential relative to the tested group of clones and we can make probabalistic statements about the stability of performance across environments for tested clones. **J. Gordon and L. Promnitz**

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PROPAGATION OF POPLAR CLONES FOR CONTROLLED-ENVIRONMENT STUDIES

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Producing *Populus* clone materials for research necessitates an efficient, reliable, uniform system of vegetative reproduction: efficient, in the sense that there be little time lag between demand and material availability; reliable, in that materials should be available with reasonable expectation of success; and uniform, in that growth studies should not have to cope with a great deal of variability in plant size, form, and vigor.

We have developed a system using greenhouse culture of stock plants, and an intermittent-mist system for vegetative propagation of softwood tip cuttings. The system described here may prove practical not only for research, but for nursery production and forest industry intensive-culture systems. We have also begun development of a tissue culture, nutrient-film technique method of poplar propagation, which provides savings in propagating "easy" poplars, and hope for mass propagation of "difficult" ones.

Intermittent-Mist Facilities

Propagation of leafy cuttings requires that a high-humidity environment be maintained. Without such an environment leafy cuttings quickly become stressed, and fail within minutes.

The intermittent-mist system maintains a film of water on the leaf surface from the time of sticking (placing new cuttings in the mist bench) until roots are well established. An intermittent mist is desirable to reduce excessive leaching of nutrients from the leaves that would result from a continuous mist. The system is composed of a bench, water source, line strainer, solenoid valve, mist line, nozzles, and a control unit.

1. We use elevated **benches** made with asbestos bottoms and sides, supported by a galvanized pipe structure. This construction is preferred over wood because of the continual wetting of the surface from the mist, and because algae accumulations can be more easily cleaned from the metal and asbestos surfaces. The pipe frame also allows better air circulation under the benches.

Bench dimensions can be adjusted to meet the needs of the operation, size of the propagation area, available water pressure, and spread of the mist nozzles selected. In a 20- x 20-foot greenhouse bay, three benches (18 x 2.5 x 0.5 feet) will fit nicely. This provides ample working space between benches and adequate access to the perimeter of the benches. A bench height of 45 inches provides a comfortable work area.

2. The **water source** is important; water high in calcium and magnesium salts will result in unsightly and perhaps detrimental accumulations on leaf surfaces. Although often not economically practical, steam distillate as a by-product of the greenhouse heating system makes an excellent choice. Where standard water sources are unacceptable, another alternative is to construct a rainwater impoundment. Water cycled through a water softener should not be used.

3. **Line strainers** with 100- or 200-mesh screens should be placed in between the water source and any booster pump, solenoid valve, or mist nozzle. The strainer filters out damaging particles and thereby protects mist system components.

4. The **solenoid valve** is an electrically activated valve in the water line. Its function is to provide an intermittent flow of water, and it is interconnected with the control unit. Two types of solenoid valves are available: normally open and normally closed. The normally open type is preferred if power interruptions are expected. Because it opens when the current is interrupted, a power failure will not desiccate the cuttings—the mist will run continuously

as long as the power is off. Waterproof solenoid valves are also desirable. This can be accomplished by covering the valve coil with a silicone sealer. The solenoid valve should be located below the level of the mist line to avoid dripping of the mist nozzles during the off cycle.

5. The **mist lines** may be made of iron pipe, PVC (plastic), or copper. The lines should be of sufficient diameter to serve the pressure needs of the system. Several commercially available mist systems may be selected, depending on preferences dictated by use, durability, and initial cost.

PVC has become increasingly popular because of its ease of assembly and low cost. Iron pipe is difficult to fit. Copper tubing is initially more expensive, but is durable, fairly easy to work with, and is essentially trouble-free. Also, copper fittings are readily available through local plumbing supply outlets.

6. Two general types of **mist nozzles** are available: deflection and oil burner. Deflection nozzles operate by water striking a flat surface, which may be simply a wire located above the orifice, or a solid metal or plastic deflection plate. Several types of deflection nozzles are available. Some are specially constructed for PVC systems, and all are relatively trouble-free. Oil burner nozzles work on a principle of whirling the water through the orifice. This type, though often more expensive, is very durable, particularly when equipped with a stainless steel tip. The oil burner nozzle is also better suited for situations requiring water conservation, since the deflection nozzle uses considerably more water. Oil burner nozzles work well at 30 psi, while deflection nozzles may require 50 to 60 psi to obtain the fine mist desired.

The nozzles may be placed on the mist line in a number of ways. Some are positioned on risers sufficiently above the line to clear the plant materials, while others may be positioned on overhead lines directed downward. Another method is to elevate the mist line, with the nozzles teed from the line upward, to provide a uniform umbrella of spray over the bench surface. The line can be located approximately 10 inches above the bench, with the tee and nozzle extending an additional 5 inches. This provides excellent access to the bench without interference from lines and nozzles. It allows for maximum distribution of the mist spray, and the line is easily reached for maintenance without disturbing plant materials on the bench. Overhead lines with nozzles directed downward tend to drip more freely, and the mist line must be recharged with water with each "on" cycle because of water lost through dripping. This ca problems with uniformity, because the nozzles activated beginning with the nozzle closest to water source and progressing outward.

Depending on the type of mist nozzle selected, zles should be spaced from 2.5 to 3 feet apart. primary consideration is to provide uniform cove over the surface to be misted. Natural drafts drafts associated with the heating and air circula systems may make closer spacing more desirab

7. The **control unit** must regulate the mist so that leaf surfaces of the cuttings are wet a times. Five general types are available: (a) electr leaf, (b) thermostat, (c) counter- balance, (d) ph lectric, and (e) clock.

The **electronic leaf** is a sensor made up of electrodes. As the water film evaporates from its face, simulating a leaf surface, the electrical cur between the electrodes is broken, activating the cycle until the surface is wet again.

A **thermostat** control monitors the tempera of the leaf surface. As the water evaporates, the perature rises to a critical level, activating the cycle.

The **counter-balance** control is regulated simulated leaf surface, normally a wire screen face. This is counter-balanced with a weight at opposite end; the assembly is then hung on a fulc with a mercury switch to activate the solenoid water evaporates from the screen, the imbal causes the weight to shift, allowing the mercury sw to turn on the mist system. Algal and metallic accumulations cause this system to lose its prec over time and periodic cleaning of the screen is essary.

Photoelectric cells work on the relation of intensity and evapotranspiration—the higher light intensity, the more frequently the mist cyc activated. They are used, but not commonly.

Control units utilizing **clocks**, which ma hooked together to provide just about any uni mist cycle over a 24-hour period, have been suc fully employed by many propagators. Normally clocks are hooked together to provide on and of riods for day and night, and mist cycles within on period of about any duration desired. This sy has been employed by Iowa State Universit searchers and has proved most reliable. One clock is used for the 24-hour daylight sequence with the second clock providing 30-second mist bursts.

Different mist cycles will be dictated by environmental factors such as relative humidity, light intensity, and temperature. Closer frequencies, even continuous mist, may be required during summer months. Fresh, succulent cuttings may require a continuous mist for the first 2 or 3 days during daylight hours. High temperatures and light intensities in late spring and summer cause stresses on the fresh cutting that must be neutralized. *Populus* cuttings do not appear to be severely affected by nutrient leaching that would otherwise make a continuous mist undesirable. For most circumstances, a cycle of 30 seconds on and 30 seconds off is adequate.

The interval between mist bursts may be lengthened during winter. Thirty seconds on and 2.5 minutes off has worked successfully, but propagators must vary the cycle according to weather and condition of cuttings.

Misting during the dark should be avoided when possible to prevent disease. In practice, however, dark-period misting may be necessary, particularly during the winter when the heating system can lower relative humidity considerably. One or two mists during the dark period is ordinarily sufficient.

The primary purpose of the intermittent-mist system is to allow as much light as possible without stressing the cutting. However, shading may prove desirable during high light intensity periods of early summer. Shade cloth can be hung above the bench, but it should be high enough to ensure good air movement within the cuttings. Incandescent lights to extend the photoperiod to 18 hours are also used.

Special circumstances, or individual preferences, may require mist durations of less than 30 seconds. For example, cuttings propagated with flower buds intact, although ordinarily not acceptable, may be needed for hybridization studies. A 30-second mist provides too much moisture and will damage the catkin. An additional timer allowing 1- or 2-second bursts can be added to the system to accommodate such special situations.

Bottom heat provided by thermostatically controlled soil cables is helpful, especially during winter. Air temperatures of 21 to 24°C and bottom heat temperatures of 3°C higher than air work well. The bench temperature does not appear significant during late spring and summer propagation periods. This is probably due to the propagation medium absorbing heat and naturally retaining somewhat more warmth than the surrounding environment.

Stock Plants

A reserve of stock plants must be maintained in the greenhouse to supply cuttings. A schedule should be established to provide suitable cuttings whenever they are needed.

A good cutting comes from a vigorous stock plant showing no signs of disease or serious insect infestation. Although succulence leads to susceptibility to pathogen attack, it is the nature of *Populus* that vigor and succulence are virtually inseparable. Because some succulence will have to be accepted, lateral cuttings are preferred over apical. The carbohydrate-to-nitrogen ratio has been suggested as the primary influence related to succulence and rooting ability. High nitrogen and low carbohydrate concentrations provide soft, succulent tissues that often develop stem rot. This may be offset somewhat by using lateral shoots as previously suggested, by reducing fertilization somewhat, and by reducing the amount of water provided the stock plant.

To provide a continuous supply of cuttings through the year and to maintain stock plant vigor, a rotation schedule should be followed. Stock plants are most productive if changed every 4 or 5 months. The 4-month schedule offers the most cuttings over time, with the 5-month schedule extending the use of the stock plant for one more cutting collection.

A 4-month rotation can be set up to provide cuttings every 3 weeks throughout the year. This will accomplish the objective of having plant material available for propagation without undue delay. The 4-month rotation involves eight actual rotations within a 12-month period. The sequence of 4 weeks, 6 weeks, 3 weeks, and 3 weeks, illustrated below, is standard. The number of rotations can be adjusted to fit the needs of the operation.

- Week 1—Start cuttings to be used for rotation I.
- Week 4—Pot rooted cuttings as stock plants for rotation I. Grow for 6 weeks, pruning lateral branches as needed to provide a single stem. Height at 6 weeks should be 60 to 80 cm.
- Week 10—Decapitate approximately 20 cm from stem to force lateral growth on rotation I.

- Week 13—First cuttings should be available from rotation I plants. An average of seven cuttings per stock plant can be expected from this first cutting. (See section on clonal differences.) At this point the stock plant should be pruned to two to four strong laterals. The selected laterals must be headed back to approximately 15 cm, with four to five available buds per lateral for forcing a second cutting.
- Week 16—Second cutting of rotation I. An average of 10 cuttings per stock plant can be expected. At this time the stock plant can be cut back to approximately 25 cm, with any lateral shoots below this height pruned off, provided there are buds remaining for additional growth. This will allow a few more cuttings in another month. The stock plant is preferably discarded at this point, in favor of the better cuttings that will be available in 3 weeks from rotation II plants.

Annual Rotation Schedule

Rotation I
Jan. 1—Start cuttings
Feb. 1—Pot rooted cuttings
Mar. 15—Decapitate
Apr. 7—First cuttings
May 1—Second cuttings

Rotation II
Feb. 15—Start cuttings
Mar. 15—Pot rooted cuttings
May 1—Decapitate
May 21—First cuttings
Jun. 15—Second cuttings

Rotation III
Apr. 1—Start cuttings
May 1—Pot rooted cuttings
Jun. 15—Decapitate
Jul. 7—First cuttings
Aug. 1—Second cuttings

Rotation IV
May 15—Start cuttings
Jun. 15—Pot rooted cuttings
Aug. 1—Decapitate
Aug. 21—First cuttings
Sep. 15—Second cuttings

Rotation V
Jul. 1—Start cuttings
Aug. 1—Pot rooted cuttings
Sep. 15—Decapitate
Oct. 7—First cuttings
Nov. 1—Second cuttings

Rotation VI
Aug. 15—Start cuttings
Sep. 15—Pot rooted cuttings
Nov. 1—Decapitate
Nov. 21—First cuttings
Dec. 15—Second cuttings

Rotation VII
Oct. 1—Start cuttings
Nov. 1—Pot rooted cuttings
Dec. 15—Decapitate
Jan. 7—First cuttings
Feb. 1—Second cuttings

Rotation VIII
Nov. 15—Start cuttings
Dec. 15—Pot rooted cuttings
Feb. 1—Decapitate
Feb. 21—First cuttings
Mar. 15—Second cuttings

This system conserves space, since there are never more than two sets of stock plants on hand at any time. As the second cutting is made, stock plants can be discarded and replaced with materials scheduled from the mist bench. It should be noted that there is a 1-week discrepancy between the propagation date for stock plants and first cuttings available from two rotations behind. For example, cuttings for January 1 (Rotation I) must be taken from cuttings scheduled for January 7 (Rotation VII). Ordinarily, there are enough good cuttings after 2 weeks' growth to provide for the few that will be needed for replacement stock plants.

Rotations such as this have been kept active for several years with no apparent degeneration of the clone. However, it is a good practice to annually renew each of the stock clones using cuttings obtained from field-grown clonal orchards. Care should be taken not to introduce pathogen infections from field-grown materials.

The rotation described has some inherent unpredictability. The average number of cuttings taken from either the first or second propagation is usually as indicated. But there may be times when more stock plants will be necessary to ensure an adequate supply of good material because the number of good shoots for cuttings is less than expected. Generally it is a good idea to have as many stock plants on hand as space permits. This is especially true when preparing for field studies where scheduling may be critical.

Most of the principles of rotation scheduling can also be applied to field-study scheduling. The field study is especially critical, because planting dates are often unyielding. The first rule in field studies is not to rely on hardwood cuttings as a shortcut for stock plant material. Hardwood cuttings may be rooted and in cutting production 6 weeks before the standard stock plant is ready, but growth is often much more procumbent, requiring two or three stakes per pot. The lateral regeneration, after cutting back to force growth, is markedly slower due to a much poorer root system. Finally, the cuttings themselves are often too succulent from trying to push things too fast culturally.

A production schedule for field planting may look something like the following:

March 1—Start cuttings to be used as stock plants
April 1—Pot rooted and weaned cuttings as stock plants
May 6—Cut to force first shoots
May 19—Cut to force second shoots
June 6—Take cuttings
June 20—Cuttings rooted, begin weaning
June 26—Cuttings ready for planting

One final note on stock plants: As may be evident from the above schedule, growth is often somewhat faster during spring than during the rest of the year.

Rooting Medium

A rooting medium should be porous enough to allow good aeration, uniformly retentive of moisture, and physically able to support the cutting. A great variety of plantable containers satisfy these criteria. The Jiffy-7[1] peat pellet is one of these, and has provided excellent results for *Populus* cuttings.

The Jiffy-7 (No. 700) is composed of peat with a small amount of added nutrients, bound in a plastic mesh net. It stores as a wafer 1-3/4 inches in diameter by inch thick. This saves storage space in the greenhouse. When water is added it expands to 1-3/4 inches in diameter by 2 inches thick. The pellet has a pH of 5.5 to 6.0.

The real advantage in rooting cuttings in the Jiffy-7 is that the complete unit is plantable upon root initiation. The rooted cutting can be moved from the bench to the pot or field location with very little root disturbance, thus avoiding much of the transplant shock associated with bare-root methods.

The propagation bench should be filled with horticultural, coarse-grade perlite. This may also be used as a rooting medium for special use situations where a plantable container is not desirable. In addition, the perlite provides a sterile bed for the cuttings in Jiffy-7's to rest on. The emerging roots can continue into the perlite without danger of desiccation.

Making and Rooting Cuttings

Three types of cuttings are associated with propagation of woody plant materials: (a) softwood, (b) semi-hardwood, and (c) hardwood. Each requires a different technique, although much of the operation is the same.

Softwood cuttings, sometimes called "greenwood" or "softwood tip" cuttings, are used in the majority of research applications. Studies involving top growth comparisons where form and initial uniformity are important require softwood cuttings.

Attention must be given to propagating in a sanitary environment. The bench and perlite should be sterilized with a dilute household bleach solution prior to setting out the Jiffy-7's. The peat pellets are placed on the bench after running the mist system for an hour or two to leach out any remaining bleach. The peat pellets should be spaced to allow plenty of room for air circulation between the cuttings and to minimize leaf overlap after the cuttings have been stuck. As an example for spacing, a bench 2.5 x 18 feet will accommodate 700 peat pellets. This provides 9.25 square inches per peat pellet, or one pellet in the center of a 3- x 3-inch area. Adequate space is extremely important, since closer spacing almost invariably results in pathogen problems, particularly stem rot.

After the peat pellets have been placed, the mist system is again turned on to a constant mist and allowed to run for another hour or two until the Jiffy-7 is thoroughly expanded and uniformly wet. The peat pellets are then dibbled, being careful not to insert the dibble much more than three-fourths of the way through the pellet. Otherwise, the cutting may be inserted through the pellet, producing an undesirable rooting environment. Dibbles made of nylon are available through horticulture suppliers. The nylon keeps the peat from sticking to the dibble, thus avoiding tearing up the pellet. The dibble should be inserted and given a slight twist before extracting.

After the pellets have been dibbled, a drench of Captan wettable powder fungicide should be applied. Use 8 teaspoons per gallon of water per 100 square feet, and apply over the surface of the pellets and entire bench surface using a sprinkling can. The propagation medium is now ready to accept the vegetative cuttings.

A few easily obtained items for taking (or making) cuttings should be assembled. These include single-edge razor blades, a rubber stopper (size 11 or 12), two plastic beakers (1,000 ml), and a lab cart for a working surface.

Razor blades are suggested rather than pruning shears, because they are sterile and provide a much cleaner cut. The cleaner cut allows less vascular damage, better water and nutrient uptake, and less general tissue damage that might provide pathogen entry. The razor blades should be changed at least every 50 cuttings, and even from plant to plant if there is any suggestion of disease in the stock plants. (Sometimes it may be necessary to propagate suspect plants to find out if their disorder is pathogenic or physiological by growing new ramets.)

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[1] *Mention of trade names does not constitute endorsement of the products by the USDA Forest Service.*

A rubber stopper is used as a backing to ensure a clean cut. The stopper tends to keep the plant, and not fingers, properly positioned for severing.

Two plastic beakers are used when there are two or multiples of two people making cuttings. One person prepares the cuttings and keeps them fresh by inserting them in a beaker containing water. The second individual takes this beaker (with 30 or 40 cuttings) to the mist bench and sticks the cuttings. The person making cuttings can then continue with the second beaker. The person sticking cuttings returns with the empty beaker, rinses it out and refills it with fresh tap water. The use of water in a beaker is contradictory to some sanitation principles. But, due to the extreme succulence of most *Populus* cuttings, methods such as wet toweling do not work well. The fresh cuttings will droop from wilt in a very short time if not kept in water. Working with clean hands and not smoking while taking cuttings are other important sanitation axioms that should be observed.

The lab cart provides a handy place to keep the razor blades and beakers. The cart can also be used as a receptacle for leaves trimmed from the cutting. Trimming the cuttings over the cart is more convenient than cleaning the floor after the job is finished.

The cuttings should be taken when possible from lateral growth on the stock plant. Terminal cuttings may root, but generally do not make good propagation material. If the rotation schedule for stock plants is followed, the first and second cutting dates will only have lateral growth available anyway. A 4-inch cutting is normally selected, although sometimes during early summer a 3-inch cutting may be preferred. The shorter cutting has less tendency to stress with the accompanying droop. The smaller cuttings will survive this stress better, have less overlap in the bed from drooping, and stand up under the rigors of field planting more satisfactorily. In either case, leaves should be removed from approximately two-thirds of the stem, retaining the leaves at the apex. The pruning of leaves should in most cases be done with a razor blade. The removal of leaves reduces transpiration and limits leaf overlap in the bench. Overlap should be avoided as much as possible because the mist may not reach some leaves and leaves sticking together often decay.

Cuttings should be taken, whenever possible, in the morning when the stock plants are fully turgid. This usually means sometime prior to 10:00 a.m. Ar alternative is early evening or at night, providin the stock plants have been watered and are not unde any transpiration stress. Cool, cloudy days are als good for making cuttings.

Usually, however, the mist system should be operating during sticking. On cloudy, cool, humid day one may stick the cuttings without the mist systen being on, except while the "sticker" is out of th propagation bay collecting another batch of cuttings

In sticking the cuttings, the peat should be firml tamped around the stem of the cutting. It is important that there be good contact on as much of th stem within the pellet as possible.

Our experience has shown that with softwood cuttings, with few exceptions, no hormone treatment i necessary. In fact, treating with hormones often results in stem burn and accompanying rot. One exception may be the Crandon clone (NCFES 5339) Crandon can be propagated without hormones, bu seems to respond favorably to a 500-ppm IBA solution applied as a dip.

There is evidence that Captan, used as a fungicide, may have an additional benefit to the cutting With some species, fungicides and particularly Captan, seem to have a hormonal effect in stimulation of rooting.

Rooting for most clones will take place in abou 2 weeks. It is preferable to allow 3 weeks befor transferring to the container. Some clones, such a NCFES 5323, 5377, and 5339, may need 3 weeks t properly root. This may vary with rooting conditions Generally, one should allow an additional week t wean the cuttings from the mist. Weaning involve reducing the mist frequency gradually down to onc every 15 minutes. For example, change from 30 seconds on and 30 seconds off, to 30 seconds on and 5 minutes off for the first 2 days. The second 2 day increase to 10 minutes off. Increase to 15 minute off for the last 2 or 3 days.

If the cuttings are going to the field, this hardening-off process should be given special attentio Be sure the cuttings will be able to survive befor subjecting them to a field environment. Any shadin that has been provided should also be removed fo at least a week prior to field planting. Hardene materials, however, can be placed in the shade for few days, such as under a greenhouse bench if such accommodations are available. A watchful eye an a fog nozzle can prevent damage to newly potte trees retained in the greenhouse. This care is seldom practical in field plantings, which again emphasizes the need for special care in hardening materials for such use.

Semi-hardwood cuttings are actually stem-section cuttings that include at least one node and internode segment. These cuttings, if taken from actively growing greenhouse stock plants, will root easily. Their use is generally limited to studies where form is not a factor. Similar cuttings can be taken from field-grown trees during late summer or early fall. In this case, it is advantageous to use a rooting hormone. Such nongrowing cuttings will usually root, but there may be some difficulty in forcing new bud growth.

Hardwood cuttings can also be rooted under the mist. Late-season cuttings—taken when buds are swelling—may even require mist propagation. The advanced stage of bud development will usually result in the cutting leafing out before the roots are sufficient to support transpiration.

For hardwood cuttings it is desirable to either stick he cutting directly into the perlite, or partially bury he peat pellet containing the cutting. This allows better response from the soil cables. In some cases, when treated this way roots may emerge in 3 or 4 days. Ordinarily, if cuttings are taken during the winter months, there is no need for the assistance f a mist system. Cuttings may be stuck directly into he container or field-planted when conditions are avorable.

By far the most cuttings for research are estabished as softwood cuttings, unless a large cutting rchard has been established to provide hardwood uttings for some field applications. Nearly 100 perent success can be expected from softwood cuttings ropagated as described. As a cushion, an additional 0 percent can be started to allow for some selection t time of planting.

Outplanting

Assuming that the rooted cuttings have been adquately weaned from the mist environment, the next tep may be planting them to establish a field study. ome protection should be provided in transportation to the planting site. If transported in an open truck bed, winds will severely desiccate and bruise leaves if the materials are not covered.

When planting the cutting it is important to be sure the root system is well distributed and not twisted. Otherwise, the young tree will develop roots that will encircle and eventually strangle the remaining roots. Poor root arrangement will also favor windthrow.

Where irrigation is available the trees should be "watered in". This helps to reduce stresses associated with transplanting and serves to settle the soil around the root system uniformly.

Clonal Variation

Clones used in vegetative propagation have shown variation in: (a) the number of available cuttings from the stock plants and (b) time required to root.

Clone	Cuttings Available Per Plant—First Cutting Mean number/stock plant	Range
5377	7.7	5-12
5321	6.9	5-10
5323	7.4	5-10
5328	6.1	5-10
5339	7.6	5-10
5260	9.4	6-13
5351	7.8	6-11

Clone	Cuttings Available Per Plant—Second Cutting Mean number/stock plant	Range
5377	11.1	7-16
5321	11.3	10-15
5323	10.4	8-13
5328	9.0	8-11
5339	11.9	8-15
5260	7.1	5-9
5351	9.0	6-13

Differences in time required to root are closely associated with rooting ability and general rooting success. Clone 5260 can be expected to root in 10 days and rarely has difficulty in getting established. Most clones will root in approximately 14 days. Clones 5323 and 5377 may lag behind by 5 to 7 days; they generally are more difficult to root, and have occasional stem rot difficulties. Clone 5377 is somewhat slower than 5323. Clone 5339 (Crandon) is the most difficult to root, although it seldom takes longer than 4 weeks. The difficulty with the Crandon clone is probably associated with its aspen and European white poplar parentage. Clone 4877, a *P. alba* clone, is very similar to 5339. Neither 5339 nor 4877 will root with much success as hardwood cuttings.

The intermittent-mist system provides the production manager a relatively simple way of producing a large number of genetically and physically uniform plants in a limited space. The simplicity of the system also allows minimally trained personnel to do the work with high probability of success.

Propagation of Poplars by Shoot Apex Culture and Nutrient Film Technique

Plant tissue culture offers a form of vegetative propagation that may be able to overcome some of the problems encountered in the standard methods of woody plant propagation. Shoots have been initiated on callus cultures of a number of woody plants. Several reviews are available (Durzan and Campbell 1974, Pierik 1975, Winton and Huhtinen 1976). The production of shoots from callus cultures, however, has several limitations. Shoots may appear irregularly and in limited numbers on the callus. For this reason, the production of large numbers of woody plants is not usually possible.

A second problem with shoots produced on callus cultures is that callus tissue in culture tends toward endopolyploidy (Murashige and Nakano 1965, Partanen 1963). This increase in the ploidy level in culture may result in the loss of totipotency, the ability of every individual cell in a plant to regenerate a complete plant. Perhaps more importantly, polyploidy may result in production of a plant genetically different from the original plant, and hence the loss of the originally desired characteristics.

The culturing of shoot apices has been used in the large-scale, clonal propagation of a wide variety of herbaceous, horticultural plants (Murashige 1974). By using shoot apices of Gerbera daisy, the production of 1 million plants from one original shoot apex in 1 year is possible (Murashige 1974). The shoot apex is perhaps the most totipotent part of the growing plant. The cells of the shoot apex are less differentiated and more uniformly diploid than those of most other parts of the plant (D'Amato 1952, Partanen *et al.* 1955). Thus, the production of only a few polyploid plants would be expected in plants regenerated from shoot apices, and this has been demonstrated (Hasegawa *et al.* 1973, Murashige *et al.* 1974).

Because shoot apex culture offers a system for the large-scale clonal propagation of herbaceous plants, we attempted to determine if the same basic techniques could be applied to the propagation of woody plants.

Culture medium

The complete medium consisted of an inorganic and organic portion. The inorganic portion was the basic Murashige and Skoog (1962) inorganic salt mixture. Phosphate was added to this (170 mg/1) in the form $NaH_2PO_4 \times H_2O$. The organic portion consisted of 0.4 mg/1 thiamine HC1, 80 mg/1 adenine sulfate, 100 mg/1 myo-inositol, 20 g/1 sucrose and 10 g/1 Difco Bacto agar. To determine the most effective hormone combination for the multiplication of shoots, 30 combinations of five levels of indoleacetic acid (IAA) (0.0 M, 5.7×10^{-8}M, 5.7×10^{-7}M, 5.7×10^{-6}M and 5.7×10^{-5}M) and six levels of benzylaminopurine (BAP) (0.0 M, 1.3×10^{-7}M, 1.3×10^{-6}M, 1.3×10^{-5}M, 6.6×10^{-5}M and 1.3×10^{-4}M) were tested.

The IAA and BAP were dissolved in water by heating in an autoclave for a few minutes and then added in the appropriate amounts to the medium to produce the 30 hormone combinations. The medium pH was adjusted to 5.7 with 1 N KOH or HC1. The sucrose and agar were then added and dissolved by heating in an autoclave, and 25 ml of the medium was poured into each 25- x 150-mm culture tube. The tubes were capped with Bellco Kaputs and all components were autoclaved together at 121°C for 15 minutes.

Plant material

Shoot tips of *Populus tristis* x *P. balsamifera* cv. Tristis #1 (NCFES 5260) were used in this study (Cram 1960). They were collected in mid-August from a plantation near Ames, Iowa. All leaves were removed and the shoot tips were washed in a detergent solution. Surface sterilization was found to be unnecessary. The bud scales and all but the last pair of leaf primordia were removed under a dissecting microscope. A shoot apex 1- to 2-mm tall was planted in each tube of culture medium.

Multiplication of shoots

Tubes containing the excised shoot apices were placed in a growth chamber with a day temperature of 24°C and a night temperature of 18°C. The irradiance was 90.0 microeinsteins/m^2 sec^{-1} and was supplied by fluorescent lamps for 14 hours of every 24.

After the first 2 to 3 weeks in culture, some of the apices had senesced and died, while others had grown to five to six times their original size. Some of the treatments stimulated the formation of small amounts of callus where the base of the original apex came in contact with the medium. After 3 to 4 weeks in culture, some of the apices initiated small green areas of organized growth on the callus. These areas continued to grow and became the sites for the formation of adventitious buds that developed into adventitious shoots.

These adventitious shoots occurred where treatment consisted of 1.3 x 10^{-7}M, 1.3 x 10^{-6}M, and 1.3 x 10^{-5}M BAP with 0.0 M, 5.7 x 10^{-8}M, 5.7 x 10^{-7}M, and 5.7 x 10^{-6}M IAA. The largest number of shoots occurred when the medium contained 1.3 x 10^{-6}M BAP and 5.7 x 10^{-7}M IAA.

This treatment produced an average of 8 to 12 adventitious shoots from each original shoot apex, and it was selected as the medium for all further shoot multiplication experiments. The adventitious shoots developed on the callus at the base of the original apex, and as they grew, they produced a mass of leaves that surrounded the original apex. These shoots typically grew as a whorl of leaves without well-developed stems. The stem internodes failed to elongate on the shoot multiplication medium, perhaps because of the high level of cytokinin.

These adventitious shoots could be divided and placed on fresh multiplication medium, which resulted in the initiation of new adventitious shoots without the formation of an intermediate callus. Again, the shoots consisted only of a whorl of leaves without well-developed stems.

Rooting of shoots

To induce root formation on the multiplied shoots, the basal medium was modified by the omission of both the adenine sulfate and the additional phosphate. Also the rooting medium did not contain any BAP. Six levels of IAA (5.7 x 10^{-7}M, 5.7 x 10^{-6}M, 2.8 x 10^{-5}M, 5.7 x 10^{-5}M, 1.1 x 10^{-4}M, and 2.8 x 10^{-4}M) were tested for their ability to initiate roots. Later, six levels of indolebutyric acid (IBA) (4.9 x 10^{-7}M, 4.9 x 10^{-5}M, 2.5 x 10^{-5}M, 4.9 x 10^{-5}M, 9.8 x 10^{-5}M, and 2.5 x 10^{-4}M) were also tested for their ability to initiate roots. Shoots to be rooted were placed in 117.6-cm^3 french square bottles containing 40 ml of rooting medium. Cultures were placed in a growth chamber with a day temperature of 24°C and a night temperature of 18°C. The irradiance was 125.0 microeinsteins/m^2 sec^{-1} supplied by a mixture of fluorescent and incandescent lamps for 14 hours of every 24.

When adventitious shoots were placed on a rooting medium containing either 5.7 x 10^{-7}M or 5.7 x 10^{-6}M IAA, without any BAP in the medium, the internodes of the stems began to elongate, producing normal-looking stems. None of these shoots, however, formed roots even after 5 weeks on this medium. IBA was tested because of its ability to stimulate roots on cuttings of many plants. In the presence of 4.9 x 10^{-7}M, 4.9 x 10^{-6}M, 2.5 x 10^{-5}M, and 9.8 x 10^{-5}M IBA, shoot internodes elongated and roots were formed. The 4.9 x 10^{-7}M IBA treatment resulted in formation of the most normal-looking root system, complete with lateral roots. A second rooting experiment was conducted to determine the optimal IBA concentration for root formation. IBA was applied at 0.0 M, 2.5 x 10^{-7}M, 4.9 x 10^{-7}M, 2.5 x 10^{-6}M, 4.9 x 10^{-6}M, 1.2 x 10^{-5}M, and 2.5 x 10^{-5}M. Again, the 4.9 x 10^{-7} IBA treatment resulted in the formation of the most normal-looking root system.

Once the roots begin to appear on the shoots on the rooting medium, they should be transplanted to minimize the damage done to the root system during transfer. Rooted shoots were removed from the bottle of rooting medium and, after the medium was washed from the roots, planted in a peat pellet placed under a shaded, intermittent-mist system in the greenhouse. In this way, plants could be "hardened off" gradually to the environment outside the culture bottle. Once plants were hardened off they were moved to a Nutrient Film Technique (NFT) (Cooper 1975) system for further growth.

Applications

Tristis #1 is routinely propagated by rooting shoot tip cuttings. In this way, one shoot tip cutting can produce one complete plant in 2 weeks. By using excised shoot apices, however, each Tristis #1 apex can produce between eight and 12 adventitious shoots in 4 to 6 weeks, each of which can be rooted to produce a complete plant. If the adventitious shoots are divided and placed on fresh multiplication medium instead of rooting medium, each shoot can produce another eight to 12 adventitious shoots. Thus, the number of shoots increases geometrically each time the shoots are subcultured.

In shoot apex propagation of Gerbera daisy, each subculture results in a fivefold increase in the number of shoots, and if the subcultures are made every 4 weeks, 1 million plants can be produced in 1 year (Murashige *et al.* 1974). Similar results have been obtained by using the runner apex of Boston fern (Burr 1976). One runner apex, subcultured three times during a 5½-month period, can produce 5,000 plants. Adding a fourth subculture and extending the time period to 6½ months allows production of between 10,000 and 20,000 plants, all from one original runner apex. Unfortunately, Boston fern has not been found to be very stable in culture for long periods. The longer it is kept in culture, the greater the chance that "sports" or mutant plants will appear. When subcultured a fourth time, between 10 and 20 percent of the plants are mutants. This can be avoided simply by subculturing only three times and then starting with new cultures freshly initiated from excised runner apices.

The stability of each plant to be propagated in culture should be established before large-scale propagation is begun. Not all plants may exhibit the genetic instability of Boston fern; for example, there has been little evidence of the development of sports in the apex propagation of asparagus and Gerbera daisy (Hasegawa *et al.* 1973, Murashige *et al.* 1974). Even if sports do develop, it is a simple matter of subculturing less than the number of times when the sports become a problem. Apex propagation of Boston fern is currently done on a commercial scale in California; the cultures are subcultured only three times, and then new cultures are started. In this way, one nursery has been able to produce about 80,000 plants per month.

Because shoots are grown and multiplied in culture tubes 25 x 150 mm, a large number of shoots can be grown in a relatively small space. Cultures can be grown on shelves illuminated by fluorescent lamps mounted on the bottom of the shelf above. With this system, it has been estimated that a room 13 x 13 x 9 feet could contain about 10,000 tubes. In the propagation of Tristis #1, each tube would contain between 8 and 12 adventitious shoots, each capable of producing a complete plant. By using conventional shoot tip propagation techniques, a 13- x 13-foot space in a greenhouse could support between 150 and 200 stock plants, each of which could produce about 20 cuttings. By using shoot tip propagation, between 3,000 and 4,000 plants could be produced in this area. Shoot apex propagation using Tristis #1 has the potential of producing between 80,000 and 120,000 shoots after 4 to 6 weeks in culture without any subculturing.

Another advantage of shoot apex propagation is that because there is a multiplication of shoots in culture, fewer stock plants need to be maintained in the greenhouse. This lowers the cost of the greenhouse operation by reducing the amount of space taken up by stock plants.

The facilities for a shoot apex propagation operation consist of laboratory and greenhouse space. Ideally, the laboratory consists of separate areas for washing glassware, preparing media, transferring cultures, and growing cultures (fig. 1). The use of separate rooms for these operations greatly reduces the risk of contaminating the cultures. The glassware washing area should contain an autoclave, sink, dishwashing machine, and storage area for glassware. It should also be used in preparing plant material to be used to initiate cultures. The media preparation area should contain balances, refrigerators, a water deionizer, a pH meter, storage area for glassware and reagents, and bench space. The transfer room should have storage space for freshly prepared media and also a sterile area with either a filtered air or laminar air flow hood for initiating or subculturing cultures. The culture room should contain several sets of shelves with fluorescent lamps. Control of photoperiod and light intensity is useful. Each room should have separate controls for temperature, especially the culture room, because of the sensitivity of cultures to extremes in temperature. The greenhouse should have space for the maintenance of a few stock plants and also a shaded, intermittent-mist system for the plants after they have been removed from culture.

About 25 commercial nurseries in California presently use shoot apex propagation of herbaceous, horticultural plants. The smaller nurseries produce 10,000 to 20,000 plants per month, while the larger ones are capable of producing up to 100,000 plants per month. One of the larger nuseries propagating Boston ferns employs about 11 people and can produce about 80,000 plants per month. The initial cost

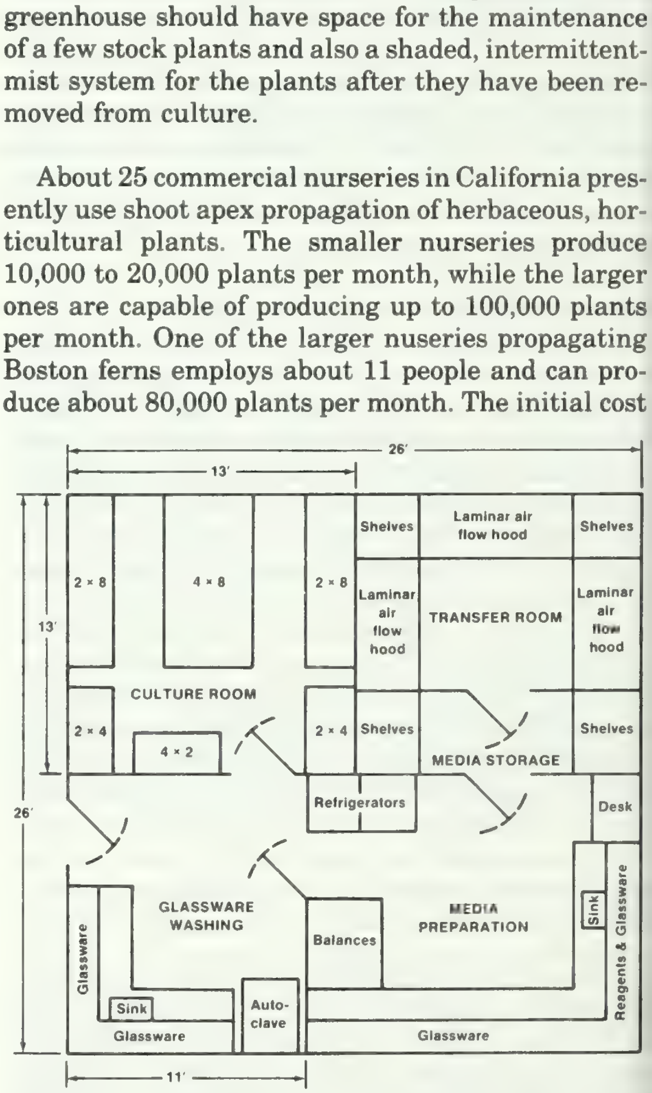

Figure 1.—*Floor plan of a hypothetical laboratory facility for the propagation of plants through shoot apex culture.*

for starting a small operation has been estimated at between $20,000 and $30,000, while a larger one would require between $60,000 and $100,000.

The low-capital-cost hydroponic technique known as Nutrient Film Technique (NFT) may have several advantages over other systems for further growth of the propagules derived from apex culture. This system is commercially used for the greenhouse culture of vegetable crops and has been advocated for production of ornamental nursery stock (Cooper 1975). Propagules in which root primordia have been induced are transferred to troughs containing trickling nutrient solution and grown until they reach a desirable size for field planting. The system is flexible in that propagules can be grown-on in containers such as Jiffy-7's or fiber blocks, or as bare-rooted stock. The latter option greatly reduces root malformation and binding that occur in container-grown stock. Bare-root plants grown in NFT gutters produce a uniform, continuous root mass which, when separated into individual plants, shows rapid root regeneration.[2] Plants could conceivably be shipped and machine-planted as a continuous strip, separated only before insertion into the soil. The advantages of NFT culture over other growing-on methods are:

1. Precise control of plant nutrition and control of diseases and insects are possible through the use of nutrient solutions containing systemic pesticides.

2. Continuous recirculation allows complete use of fertilizer and minimum evaporation loss of water.

3. Root temperatures can be precisely specified and maintained.

4. Optimal nutrition and root temperature result in better growth rates.

Gutter and other equipment for NFT system are now commercially available.

Another possible advantage of shoot apex propagation is the production of pathogen-free plants. In standard propagation of plants, the shoot tip is dissected down to an apex 1- to 2-mm tall, which consists of the apical dome and several pairs of leaf primordia. If the explant is made smaller (between 0.05- and 1.0-mm tall), a pathogen-free plant may be produced (ten Houten *et al.* 1968). The culturing of the apical dome alone makes possible the production of plants free from fungi, bacteria, viruses, viroids, mycoplasmas, spiroplasmas, and rickettsias. These organisms cause plant disease and thus restrict the growth and productivity of the host plant. The apical dome is one of the few parts of the growing plant that may be free of these organisms. Pathogen-free plants will grow rapidly after they are field-planted until they become naturally reinfested. The increased growth rate after planting, however, may be critical to the survival and subsequent growth of the plant. Plants so produced could also meet the pathogen-free requirements encountered in the international exchange of plant material, an important part of many tree improvement programs.

Apex propagation is usually easiest with both herbaceous and woody plants whose cuttings can be rooted without difficulty (Murashige 1974). This, however, does not mean that only "easy" plants can be propagated by these techniques. The shoot apex is probably the most totipotent part of the growing plant, second only to the embryo of the seed or a young seedling. Indeed, recent success in producing shoots from callus cultures of white spruce and Douglas-fir has depended on the use of excised embryos or hypocotyls of young seedlings (Campbell and Durzan 1975). The advantage of using excised shoot apices is that they can be collected from mature trees selected for their observable desirable characteristics. The use of excised embryos or seedling parts depends on the assumption that they will retain the desired characteristics of the parent tree.

Because of the totipotency of the shoot apex, propagation should be possible in a wide range of woody plants. With further experimentation, these techniques can possibly be applied to other hardwood species and perhaps, in time, to the conifers, for which standard methods of vegetative propagation have not been very successful.

Shoot apex culture offers the possibility of rapid, large-scale, clonal propagation of plants. This can be done in a relatively small amount of space, thus reducing propagation costs. However, the cost of propagating a particular plant by apex culture should first be compared with the cost of propagating the plant by existing vegetative means. Where the time required for a tree to reach seed-producing age is long and where standard methods of vegetative propagation may not be successful or practical on a large scale, tissue culture (in particular, apex culture) may offer a solution.

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[2] *Personal communication with A. J. Cooper.*

CONTROLLED-ENVIRONMENT CULTURE OF *POPULUS* CLONES

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Growing *Populus* in the greenhouse presents some challenges not ordinarily faced in greenhouse production of horticultural plants. The forestry researcher is often confronted with problems more common to nursery container production than to typical greenhouse applications. The following sections describe equipment and procedures that have been used to successfully culture *Populus* clones in the greenhouse.

Facilities

Forest researchers at Iowa State University have use of 9,000 square feet of greenhouse space under glass and an additional 2,800 square feet of headhouse space. The portion under glass is divided into 14 bays of varying dimensions, with 7,600 square feet of usable space. The headhouse provides office, laboratory, storage, and utility space.

Each of the bays is equipped with individual coolers for ventilation and cooling, ridge and sidewall ventilation, unit heaters, perimeter radiation heat, overhead electrical unistruts, a concrete floor and gutter system, and movable benches. This equipment is described in detail below:

1. Evaporative coolers of varying sizes are provided individually for smaller bays, or in pairs for larger bays. Effective cooling from April through September is essential for maintaining temperatures suitable for plant growth. Poplars respond best to day temperatures of 75°F (24°C) and night temperatures of 65°F (18°C). The capacity of the coolers is frequently insufficient for maintaining these greenhouse temperatures when outdoor temperatures reach or exceed 85°F (29°C). Shading the glass with a spray-on compound is used to compensate, but temperatures during late June through August are ordinarily too high for studies involving growth responses.

2. Ridge and sidewall, manually operated, sash ventilation systems are essential for effective air circulation and cooling. Although the greenhouse was designed to provide adequate air exchange using shutter-like exhaust vents in the curtain wall, this has proved ineffective without supplementary shading. During summer the ridge vents are opened sufficiently to allow warm air to rise and escape, when the cool air from the evaporative coolers displaces it. The sidewall ventilators are rarely used, except when there is a cooler failure, requiring natural cooling of the bay.

3. Pressurized steam unit heaters are used during the cold months for a thermostatically controlled source of heat. The unit heaters are thermostatically interconnected with the cooling system to provide a reasonably constant temperature. Equally important is the function of the heater fan in providing air movement. The unit heaters are hung overhead (9 feet), with a horizontal air draft that provides critical air circulation during both summer and winter, although during summer the steam lines remain closed. During sub-zero weather this mixing property of the unit heater is especially evident. On days when outdoor temperatures drop to zero or below, the unit heaters are unable to provide sufficient air movement below the benches. Air stratification may result in temperature differences of 30 to 40°F (-1.1 to +4.4°C) from the bay floor to the bench level of 40 inches (100 cm). Adequate temperatures normally can be maintained at the plant level, but irrigation hoses will freeze at the floor level. This points out the importance of raised benches for plant growth under acceptable temperatures. The complication that arises from trying to compensate for stratification is that trees grown on the raised benches have limited space for height growth. They may either grow beyond the artificial light source, or if directly in the path of the unit heater, suffer desiccation from the warm air flow. Additionally, mite populations may prosper on tall trees in line with the warm air movement. This problem can be alleviated by growing trees during more favorable growing periods, or by keeping taller trees out of areas in the bay subject to this warm air blast.

4. Perimeter hot (finned radiation) heat is used as a constant heat source. The amount is regulated by an outside thermostat that calls for additional heat to supplement the unit heater when temperatures fall. Heat from this source alone is not sufficient to keep bay temperatures at a desired level. It does aid in supplying a more uniform heat for the bays and is the sole source of heat in the headhouse.

5. Overhead electrical unistruts provide structural support for artificial lighting, and electrical outlets for lights and instruments.

6. Floors are concrete with a gutter and sump system at the lower end of a slight slope to provide drainage of irrigation water. Although concrete makes maintaining humidity somewhat more difficult, this liability is more than offset by its ease of cleaning, an important factor in successful sanitation. Also it is easier to move benches on rollers on concrete than on gravel or packed earth.

7. Movable benches are used in most studies to facilitate changing bench patterns within the bays, cleaning bay floors, gaining access to overhead structures and equipment, and transporting plant materials from one location to another. Each bench is constructed of galvanized pipe with 5-inch casters for wheels. The bench top, a 4-inch-high box, is constructed of redwood with inside dimensions of 2.5 by 6 feet. The bench also has a redwood pallet at 12 inches above the floor, which is useful for hardening succulent materials in partial shade before placing them on top of the bench.

Sanitation

Proper sanitation is the key to any greenhouse operation. The following rules should be observed:

1. Keep floors clean and free from algae. Periodically scrub with soap and water, then hose with a high-pressure nozzle. When weather permits venting of sidewall and ridge, sanitize by scrubbing with soap and water; then apply a dilute bleach mixture (1 pint bleach to 8 quarts water) with a watering can.

2. Periodically scrub benches with soap and water. Follow up with a rinse of dilute bleach, allow to stand for a few minutes, then rinse off.

3. Keep leaves that have fallen into pots or bench tops picked up. Remove weeds that become established in pots or benches.

4. Avoid splashing soil particles around when cleaning or watering. (This is another advantage of elevated benches.)

5. Hang up hose ends. If the breaker comes in contact with the floor, be sure to clean it prior to using for irrigation.

6. Use sterile tools when mixing soils. A dilute formaldehyde solution (1:18) works well. Keep unsanitary tools and unwashed hands out of containers full of soil.

7. Use a sterile soil medium.

8. Keep pots and flats sanitary. Wash them thoroughly after use. Do not store cleaned containers near used and contaminated containers.

9. Provide good air circulation. This seems to be particularly important. For example, it is standard practice to have only 12 2-gallon (8-inch) containers on a 2.5- x 6-foot bench. Considerably closer spacing is acceptable when trees are getting started, but space them out amply when they begin touching each other. This not only provides a less desirable environment for pathogens, but aids in miticide application by allowing more thorough coverage.

Pest Control

The most sensible approach to greenhouse pest management is to effectively control pest populations while minimizing human health hazard. With this in mind, many of the traditional pesticides have been withdrawn from use with no apparent backslide in control effectiveness.

In *Populus* culture, spider mites are the major pest. Effective control can be accomplished with Pentac miticide (Pentachloro-2, 4-Cyclopentadien-1-y1). Dosage rates of 2 level teaspoons per gallon of water, plus an added surfactant such as Triton B-1956 spreader-sticker at teaspoon per gallon, have proved effective with no apparent phytotoxicity. Application with a 3-gallon, hand-operated pressure sprayer is adequate. However, a gasoline-powered KWH Knapsack Mistblower/Duster will improve coverage and reduce application time. Label regulations should be rigorously followed, of course.

Sanitation, pest control, and adequate air circulation are interrelated. During summer, whenever possible, remove all plant materials from a bay. Clean thoroughly as previously described, spray with an ovicide, and allow the bay to "dry out" for 2 or more weeks.

Soiless Mix

Soiless mixes get around the problem of obtaining uniform soil from year to year, plus the associated complications of residual herbicides or high salt content in field soils. Originally, we selected a soiless mix using two parts Jiffy-Mix and one part coarse-grade horticultural perlite. We later tested this ratio against several other combinations of Jiffy-Mix to perlite (1:0, 1:1, 2:1, 3:1, and 0:1), with and without Mag-Amp slow-release fertilizer. The results showed clearly that a ratio of 2:1 with Mag-Amp is superior.

Soiless mixes provide the researcher with several advantages:

1. Precise repeatability of growth medium for research.

2. A sterile medium with no potential for herbicide, weed seed, insect, or pathogen contamination.

3. Expensive steam or electric sterilization equipment is unnecessary, because the mix is sterile when purchased.

4. Toxicity problems that often accompany conventional sterilization processes are avoided.

5. Ease in preparation, which again economizes labor and time.

6. Light in weight, allowing fairly large trees and containers to be moved without back-breaking effort.

7. Problems of salt accumulation are minimal due to the looseness of the mixture and free drainage.

8. Excellent, uniform air-water-particle relation.

9. Ease of storage. Roughly 50 8-inch containers can be filled with a single batch of soiless mix. This involves two bags of Jiffy-Mix and one bag of perlite. An adequate supply can be stored in a comparatively small space, without special holding bins as would be necessary for soil.

10. Season-to-season mix uniformity allows a standardized fertilization program. Trace elements, plus N-P-K in small amounts, are included in the mix.

The soiless mix is prepared by sterilizing a portion of a bay floor. Two bags of Jiffy-Mix and one bag of perlite are then dumped onto the floor. (Jiffy-Mix and perlite are obtained in 4-cubic-foot bags.) Terra-Lite brand perlite is used, because the coarse grade has larger particle size than some other brands. Perl-Gro is another brand that has been used. Some brands have a smaller particle size, in fact rather fine, and do not provide the proper knit. They tend to drain too fast as a mix, thus they do not retain nutrients well and must be fertilized more frequently. Medium granual Mag-Amp (7-40-6) at a rate of 2.95 Kg (6.5 pounds) per 12 cubic feet is then added to the pile. The components are then mixed thoroughly with a sterile shovel. Both the Jiffy-Mix and perlite have a lot of fine dust-like particles that can get into eyes or impair breathing. It is a good idea to wear a dust mask or respirator and goggles when pouring out and mixing the components. Also, any fans that could pick up the dust should be turned off.

Pots and Potting

After thoroughly blending the soiless mix components, pots and potting is the next consideration. A 1-quart aluminum scoop is ordinarily used, although a bleach bottle cut to a scoop shape also works nicely. Bronze screening material is cut into 1.25-inch squares and placed over the drainage holes of the containers. The copper in the bronze alloy helps keep the roots from escaping the pot when plants are grown for long periods. Aluminum screening can be used for short-duration studies, but should not be used for plants grown more than 2 months. Enough potting medium is put in the container to fill it to within 1 inch of the top. The peat fraction of the soil mix is difficult to wet, so at this stage, the container should be watered two or three times to settle the mix and provide uniform wetting. Settling should be to about 2 inches from the top of the pot, so that an adequate amount of water can be applied during irrigation to permit drain-through without floating out the perlite or washing out other medium components. Some of the soil should be scooped out (with clean hands) to provide a cavity for the young tree; after planting, water again lightly to settle the soil and clean up the container.

For most studies, and particularly for stock plants that may be grown 3 to 4 months, an 8-inch, 2-gallon plastic pot is suggested. Polyethylene field containers are light, durable, and reusable. Individual preferences vary concerning the use of plastic pots rather than clay. Although clay pots are porous, allowing better aeration, they also dry out faster and tend to encourage root growth along the sides of the pot rather than uniformly throughout. With soiless mixes aeration is provided by the loose properties of the medium. Plants in clay pots require watering 1.5 to 2 times more often than plants of the same size grown in plastic containers (Ball 1975). All-purpose, all-weather, heavy-duty polyethylene containers are available in sizes ranging from 1 quart to 7 gallons. Having several sizes on hand will meet the changing needs of a research greenhouse.

Irrigation and Fertilization

Because of the loose properties of soiless growth media, watering is not as critical as it would otherwise be. But do not allow this to permit laxity in one of the most important phases of plant growth. Timely irrigation according to plant size, light, temperature, and air circulation is still extremely important. Ironically, one of the most difficult things for the greenhouse manager to get across to his or her help is the importance of proper irrigation. Here is where the free-draining property of the soiless growth medium is perhaps most valuable.

Too little water applied too frequently will not allow the soil to become uniformly moist. It also will reduce oxygen penetration to the root system. Enough water should be applied to allow a small amount to drain from the pot. This flushing will leach out any salt accumulation and ensure uniform moistening of the soil. Plant size and "drying down" characteristics provide the best information on how often to water. Many of the larger stock plants may require irrigation twice daily. A good practice is to water thoroughly in the morning, then follow up in the afternoon where needed. About a 6-hour interval should be allowed between irrigations.

How the water is applied is also important. The nature of the soiless mix will indicate whether it is being done correctly. The perlite of the upper inch or so of the mix will float, and when it floats uniformly from side to side, enough water has been applied. If it floats out or is washed out by a sideways direction of the hose and water breaker, the plant is being improperly watered. The rate of water flow from the breaker should be adjusted to avoid washing the mix from the pot and the breaker should be held above the pot and aimed downward. Watering with too much force from the side will wash out the mix, distribute it unevenly within the pot, and create a sanitation problem on the bench. Irrigating until the perlite "floats" may be a little difficult to judge at first. Stating this more precisely, 1 liter of water should be applied to a 2-gallon container.

Although frequency of irrigation could be varied for individual plants, a happy medium is normally sought to avoid complicated and time-consuming adjustments. Fertilization includes the Mag-Amp slow-release fertilizer mentioned in the soiless mix section for a constant supply of nutrients. To complement this a Peters 20-20-20 water-soluble fertilizer is applied while irrigating with a 1:24 proportioner, a device that meters liquid fertilizer into a hose or irrigation system. One pound of this fertilizer is diluted in 5 gallons of water to provide, after the 1:24 proportioning, a 200 ppm N, 88 ppm P, and 166 ppm K nutrient boost. This is applied twice a week during favorable growing conditions, and once a week during cloudy winter months when watering is less frequent and salt accumulation becomes a threat.

Chelated iron is applied once a week and micronutrients are provided at about the 12-week stage of growth, or when deficiencies are noted. To avoid a precipitate, use distilled water for mixing the chelated iron and N-P-K fertilizers in the 5-gallon stock solution. Chelated iron is added at 2 ml per liter applied to the plant, or about 900 ml per 5 gallons stock solution. Micronutrients are added at 1 ml per liter applied. Half concentrations are provided newly planted rooted cuttings for the first 2 weeks. This is accomplished by saving these applications until most of the stock solution has been used, then simply adding enough water to double the existing volume. Any conifers in the greenhouse will also do better with this 100 ppm N concentration.

FeEDTA (Chelate of Iron Stock Solution) **1 ml/l = 5 ppm**

Compound	(g/l)	(g/4 l)
Iron (II Sulfate $FeSO_4 x 7H_2$)	24.9	99.6
Ethylenediaminetetraacetic acid EDTA	26.1	104.4
Sodium hydroxide NaOH	10.5	42.0

Mixing Apparatus

1. 4,000 ml beaker.
2. Magneticstirrer (use long rod magnets).
3. Aeration tube and tubing.

One-liter Preparation

1. Set up beaker on magnetic stirrer.
2. Fill beaker with approximately 900 ml distilled water.
3. Insert stirring rod.
4. Add 24.9 g $FeSO_4$ and 26.1 g EDTA.
5. Attach air tubing to air supply; couple tube with glass tubing and insert into beaker.
6. Gently aerate while mixing with magnetic stirrer for 1 hour before adding NaOH. Aerate at rate that minimizes spattering.
7. Add 10.5 g NaOH.
8. Add water to bring to 1,000 ml.
9. Continue aeration for 3 hours.
10. After the 3 hours, adjust pH to 5.0 for better storage characteristics. Normally involves adding additional NaOH.
11. Continue aeration and stirring overnight, or for several hours.
12. A **clear**, coffee-colored solution should be the final result. Store under refrigeration.

Micronutrient Stock Solution

Compound		Grams dissolved in 1 liter H_2O
H_3BO_3	Boric Acid	2.86
$MnCl_2 \times 4H_2O$	Manganese Chloride	1.81
$ZnSO_4 \times 7H_2O$	Zinc Sulfate	0.22
$CuSO_4 \times 5H_2O$	Copper Sulfate	.08
$H_2MoO_4 \times H_2O$	Molybdic Acid (assaying 85 percent MoO_3)	.02
$MgSO_4 \times 7H_2O$	Magnesium Sulfate	.20

Add 1.0 ml of this stock solution for each liter of water applied.

Element	Ppm for 1 liter nutrient solution applied
B	0.50
Mn	.50
Zn	.05
Cu	.02
Mo	.01

Lighting

Lighting consists of a very basic system of alternating incandescent and fluorescent fixtures. Spacing is approximately 3 feet apart, with the lamp 7 feet from the floor and 4 feet from the bench surface. Illuminance is only sufficient to extend the photoperiod and prohibit dark respiration, it is insufficient for active photosynthesis. The system provides for an 18-hour photoperiod from 6:00 a.m. until 12:00 midnight.

Miscellaneous Cultural Suggestions

Staking is necessary after about 2 weeks' growth. Without staking, and in the absence of winds to provide an environmental stimulus for initiating supporting fibers, the tree will grow over to one side. Increased branching will accompany this procumbent form. Four-foot bamboo cane stakes are used, with "twist-em" ties located as necessary to provide support. Tie loosely and check frequently to avoid constricting the expanding stem.

A time-saver in applying miticides is to spray only the bottom two-thirds of the tree when it gets about 3 feet high. This can be done because normally the tree will grow faster than the mites can migrate upward. It also provides an advantage in that the new, more succulent growth is not subjected to potentially phytotoxic chemicals.

The soiless mix cultural system described in this section allows essentially all clones to be treated alike, thus vastly reducing management complexities. The system not only works well with all *Populus* clones, but with most other woody plants as well, except conifers. They just do not do well with the soiless mix suggested. About the only exception to the blanket applicability of this system to *Populus* is with Tristis #1 (NCFES 5260). It does not require as much water for some reason, which in turn means it does not need to be fertilized as frequently. When fertilized like the rest, however, it does not seem to suffer.

Temperatures fluctuate diurnally between 75°F day and 65°F night as a normal reaction to light and dark periods. It has never been necessary to daily set and reset the thermostats of each individual bay.

Watering, potting, and potting mixes described for greenhouse use are equally suitable for growth-room culture of poplar clones. Nutriculture techniques for the production of uniform poplars have been described by Dykstra (1972), but are not routinely used for rapid-selection purposes.

USE OF CONTROLLED-ENVIRONMENT AND STATISTICAL TECHNIQUES TO MAXIMIZE DISCRIMINATION AMONG CLONES

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On the basis of several studies, we have established principles for deriving best estimates of growth potential differences for poplar clones from controlled environment studies. These are:

1. Environments that are most favorable for growth expose greatest differences among clonal growth potentials. Thus, long photoperiods, higher light intensities, and rich nutrient and water regimes are preferred.
2. For estimating environmental stability (the ability of a given clone to grow similarly under a wide range of environments), the use of a few, widely divergent environments is preferred to the use of a larger number of similar environments.
3. With limited controlled-environment capacity, the number of clones should be increased at the expense of a larger number of environments in selection trials. At least three environments must be included if estimates of environmental stability are to be calculated, however. Three to five replications per clone and environment are needed for materials as variable as the poplar clones used in these studies.
4. Selection efficiency, both in resource and statistical terms, increases with the number of clones included in a given trial.
5. In a time series of selection trials, a minimum of one common clone should be included in all trials as an internal standard. Internal standard clones should be good growers that are environmentally stable.
6. Elaborate environmental control systems are not necessary for early selection trials of the kind described here, in that no attempt to simulate "field" environments is called for. Repeatability and reliability are more important than varying environmental parameters over wide ranges or establishing elaborate temporal programs.
7. Photoperiod and temperature, manipulated for plants optimally supplied with nutrients and water, can provide sufficient environmental difference to expose the relative environmental stabilities of several clones. For stability across nutrient and water potential gradients, clones should, of course, be evaluated in environments differing in these parameters. Stability to specific pathogen levels could probably be evaluated in the same way.
8. At least 6 weeks are required to conduct selection trials in controlled environments, assuming clones are rooted and established in pots at the beginning.
9. Height is not well-correlated with other growth variables (e.g., leaf area, dry weight) as a rule. Thus, if ability to accumulate dry weight is of interest, dry weight must be measured—i.e., it probably cannot be predicted accurately from height measurements.
10. Total dry weight accumulation over the trial period appears to be the single best predictor of field growth potential.

Two iterations of controlled-environment selection trials for field growth potential are described below. The data from both are used to calculate selection indices. The outcome of the trial is a ranking according to estimated growth potential. Any subset of the ranked test group can be chosen for field trial. The smaller the subset, the greater will be the chance of excluding good clones and including bad ones.

Steps in a generalized trial are:

1. Decide upon specific objectives, and choose environments and measurements.
2. Assemble and propagate plant material.
3. Grow and measure clones in controlled environment.
4. Analyze variances to see if clones differ.
5. Rank clones by mean performance.
6. Do "distance" multivariate analyses.
7. Do "environmental stability" analyses.
8. Choose clone subset for field trials.
9. Do field trials.
10. Calculate field/controlled-environment correlations for use in future selection trials.

Controlled-Environment Trial I

Twenty-five *Populus* clones were chosen from those gathered by the Maximum Yield Project of the North Central Forest Experiment Station for possible use in field trials (table 1). No particular mix of parentage or origin was chosen; for some clones (e.g., 5258), no reliable information on lineage was available. (Clones 2 and 19 probably are the same; this was discovered after all the data were analyzed.)

In all three environments (Greenhouse I, Greenhouse II, Growth Chamber), apical cuttings rooted under mist were grown in 2-gallon plastic pots containing a 3:1 Jiffy-Mix:perlite artificial substrate. The growth chamber environment had the following characteristics: growth period, 6 weeks; photoperiod, 18 hours (in Percival, Model PT-80 growth chambers); and temperature, 25°C day and 15°C night. The growth-chamber environment had the least variation in photoperiod, light intensity, and temperature. Greenhouse II had a much higher temperature and a longer natural light photoperiod than did Greenhouse I. Light intensities were highest in Greenhouse II because of seasonal changes in solar position. In both greenhouse experiments natural photoperiod was supplemented with additional artificial light to extend daylength to 18 hours.

The plants were placed on benches in the greenhouse and in growth chambers at random.

Growth rates were determined from weekly total leaf counts and total height measurements (cm), beginning with initial measurements when the rooted cuttings were removed from the propagation bench. Leaf ovendry weight (g) and stem ovendry weight (g) were determined at the end of the growth period.

Table 1.—Populus *clones included in trials*

Iowa State University clone number	**North Central Forest Experiment Station number**	**Name and parentage**
1	4877	*Populus alba* L.
2	4878 (5327)	*Populus* x *euramericana* Guinier *(deltoides* x *nigra)*
3	4879	*Populus* x *euramericana* Guinier
4	5258	*Populus* sp.
5	5262	*Populus candicans* Ait. x *Populus berolinensis* Dipp.
6	5263	*Populus candicans* Ait. x *Populus berolinensis* Dipp.
7	5264	*Populus deltoides* Marsh. x *Populus plantierensis* Schneid.
8	5265	*Populus deltoides* Marsh. x *Populus trichocarpa* Torr. et Gray
9	5266	*Populus deltoides* Marsh. x *Populus trichocarpa* Torr. et Gray
10	5267	*Populus deltoides* Marsh. x *Populus caudina*
11	5271	*Populus charkoviensis* Schroed. x *Populus deltoides* Marsh.
12	5272	*Populus nigra* L. x *Populus laurifolia* Ledeb.
13	5321	*Populus* x *euramericana* Guinier
14	5322	*Populus* x *euramericana* Guinier
15	5323	*Populus* x *euramericana* Guinier
16	5324	*Populus* x *euramericana* Guinier
17	5325	*Populus* x *euramericana* Guinier
18	5326	*Populus* x *euramericana* Guinier
19	5327 (4878)	*Populus* x *euramericana* Guinier
20	5328	*Populus* x *euramericana* Guinier
21	5331	*Populus betulafolia* Dipp. x *Populus trichocarpa* Torr. et Gray
22	5332	*Populus betulafolia* Dipp. x *Populus trichocarpa* Torr. et Gray
23	5334	*Populus deltoides* Marsh. x *Populus trichocarpa* Torr. et Gray
24	5260	*Populus tristis* Fish. x *Populus balsamifera* L.
25	5377	*Populus* x *euramericana* Guinier, "Wisconsin Number 5"

Results

Clones varied greatly in all growth characteristics measured, but showed some consistency when compared across the three test environments. Total height and dry weight of leaves and stems varied widely among clones and environments (tables 2, 3, and 4).

When all clones were pooled, mean leaf and stem dry weight and total height were all greatest in Greenhouse II (table 5). The greater total solar radiation due to longer natural daylight, greater average light intensity during the longer days, and a greater proportion of clear days during the 8-week growth period all contributed to greater growth in this environment. The growth chamber means were smaller than the greenhouse means, primarily because of the shorter growth period (6 rather than 8 weeks), but also because of lower growth-chamber light intensities. Because total photoperiod was the same in all three environments, photoperiodic reactions should not have caused differences in growth among environments.

Table 2.—*Duncan's new multiple range test for significant differences in stem dry weight for the three environments (any two means not next to a common line are significantly different)*

Growth chambers		Greenhouse I		Greenhouse II	
Clone	Mean	Clone	Mean	Clone	Mean
	Grams		*Grams*		*Grams*
24	7.96	3	18.80	4	32.49
4	6.71	4	18.01	23	31.89
18	6.68	5	17.58	18	31.28
5	6.65	9	17.32	25	30.88
25	6.62	23	15.40	9	27.97
3	5.95	8	14.73	3	27.25
9	5.91	15	14.57	17	24.81
1	5.83	18	14.42	15	23.82
6	5.78	21	14.31	7	23.54
17	5.55	16	14.19	5	23.16
21	5.46	17	14.14	20	22.78
23	5.33	12	14.13	8	22.19
15	5.32	22	13.52	6	20.62
7	4.95	7	13.46	1	20.23
12	4.94	25	12.64	12	19.51
22	4.91	6	12.10	2	18.88
8	4.77	24	12.01	16	18.11
13	4.66	19	11.54	14	18.08
2	4.47	14	11.35	19	17.34
16	4.30	2	10.35	22	17.26
19	3.98	13	10.15	21	16.43
20	3.38	20	8.39	24	15.51
14	3.27	10	6.91	10	10.47
11	3.20	11	6.87	13	10.25
10	2.57	1	6.12	11	7.38

Table 3.—*Duncan's new multiple range test for significant differences in leaf dry weight for the three environments (any two means not next to a common line are significantly different)*

Growth chambers		Greenhouse I		Greenhouse II	
Clone	Mean	Clone	Mean	Clone	Mean
	Grams		*Grams*		*Grams*
9	22.37	9	32.49	23	54.88
23	19.84	8	29.71	9	49.27
8	19.52	23	29.59	8	45.46
4	19.02	4	27.38	7	43.76
25	18.63	3	27.28	4	42.99
6	18.37	7	25.36	15	39.22
18	17.75	15	24.36	18	39.01
17	17.40	5	24.33	17	37.90
5	16.96	17	23.86	25	37.27
1	16.86	18	21.75	3	36.34
7	16.77	16	21.50	14	34.63
15	16.76	14	21.32	5	32.82
12	16.06	21	21.22	20	31.44
21	15.88	12	20.44	1	31.23
24	15.51	20	20.41	2	30.69
3	15.18	19	18.42	19	29.56
20	14.85	22	18.31	12	28.73
16	14.83	2	18.04	6	28.59
13	14.28	13	17.95	16	28.26
2	13.74	25	17.93	21	26.14
22	13.60	24	17.40	24	22.07
19	12.44	6	16.94	22	21.80
14	12.09	10	13.00	10	18.59
10	10.33	1	12.85	13	17.74
11	7.90	11	9.91	11	11.45

Within each environment a high rank for one variable did not necessarily indicate a high rank for other variables. Moreover, clonal ranking based on individual variables or sums varied from environment to environment. Further analysis beyond simple ranking and summing was necessary to indicate clearly which clones had the greatest juvenile growth potential and stability across environments. Therefore, growth variables for clones within environments were subjected to analysis of variance, and differences among clones (for each growth variable in each environment) were examined by use of Duncan's new multiple range test (tables 2, 3, and 4).

Greenhouse II produced the greatest number of significant differences among clones in stem weight as well as the greatest stem weights (table 2). Seven clones produced significantly greater mean stem weight than others regardless of environment. These seven clones (3, 4, 9, 17, 18, 23, and 25) may be regarded as consistent producers of heavy stems across all environments.

Table 4.—*Duncan's new multiple range test for significant differences in total height for the three environments (any two means not next to a common line are significantly different)*

Growth chambers		Greenhouse I		Greenhouse II	
Clone	Mean	Clone	Mean	Clone	Mean
	cm		*cm*		*cm*
5	94.8	5	181.2	23	192.8
6	86.9	3	163.4	5	188.8
24	85.5	9	158.2	9	180.0
3	82.1	22	157.6	3	172.1
1	81.9	6	156.4	18	171.6
12	80.7	23	155.9	7	170.6
2	79.7	12	151.0	25	170.4
9	79.0	19	144.0	6	170.2
18	78.9	15	141.8	17	169.5
23	78.6	8	141.4	22	167.7
22	78.1	16	140.8	4	166.6
7	77.0	4	140.4	12	164.9
15	76.5	17	137.9	15	160.6
25	75.6	2	136.8	2	160.0
17	75.2	7	135.4	8	156.4
4	75.1	25	134.2	21	154.2
21	74.9	18	130.5	1	153.8
19	72.8	24	124.4	16	147.9
8	71.9	13	121.8	19	142.6
16	65.5	1	120.9	24	134.7
13	65.4	14	117.5	14	133.4
11	64.3	21	115.2	20	124.6
10	58.6	10	110.3	10	118.7
14	55.6	11	104.8	11	112.6
20	49.9	20	97.9	13	108.8

Clones producing the greatest total leaf weight were also consistent for all three environments (table 3). As with stem weight, Greenhouse II produced the greatest number of significant differences in leaf weight. Three clones, 8, 9, and 23, constituted the top group. Two of these (9 and 23) also were in the top group for all environments in stem-weight production.

Total height analysis presented a somewhat different picture. Greenhouse I produced the greatest number of significant differences in total height (table 4). But of the six tallest clones in Greenhouse I, only three (3, 9, and 23) appeared in the group showing consistently greatest stem weight, and only two (9 and 23) appeared in the group showing consistently greatest leaf weight. Thus, high potential for weight production is not necessarily related to high potential for height growth.

Leaf number increased roughly with time; therefore, regressions of leaf number on time were examined to see if rate of leaf production, as indicated by the slope of this regression line, was an indicato of final weight or height or both. If it were, it migh be possible to reduce or eliminate destructive measurement. Again, Greenhouse II produced the greatest slopes, reiterating the generally better growin conditions in this environment. There was little consistency, however, between leaf production and fina weight and (or) height. For example, clone 23, on of the best performers in terms of stem and leaf weigh and height growth, had one of the lowest rates o leaf production.

Table 5.—*Averages and ranges for leaf and stem weigh and total height for all clones pooled in each environment*

	Growth chambers	Greenhouse I	Greenhouse II
Leaf weight		*Grams*	
Mean	15.79	20.68	32.79
High	22.37	32.49	54.88
Low	7.90	5.82	11.45
Variance	15.46	39.92	55.12
Stem weight		*Grams*	
Mean	5.18	12.54	21.29
High	7.96	18.80	32.49
Low	2.57	3.04	7.38
Variance	2.72	15.10	23.69
Total height		*cm*	
Mean	74.3	134.7	155.7
High	94.8	181.2	192.8
Low	49.9	82.5	98.8
Variance	68.24	25.79	219.28

Controlled-Environment Trail II

Growth chamber procedures

The experiment was conducted in Percival, Mode PT-80 growth chambers. The average light intensit at the top of the plant crowns was maintained a approximately 3,000 foot-candles. The relative humidity was not controlled. Plants were watered t the saturation point (water dripping out the pot bottom) once every 2 days. Each week every pot wa flushed with demineralized water followed by 20 mls of the prepared nutrient-micronutrient solutior The temperature was controlled to within ±2°C an the photoperiod to within ±15 minutes. Row temperature treatments with day temperatures (D) an night temperatures (N) corresponding to light an dark (D) portions of low light treatments, making total of 16 treatment combinations, were randoml assigned to growth chambers. Temperature treatment levels were: 17D-5N, 23D-11N, 29D-17N, 35D 23N; light treatment levels were: 12D-12N, 14D-10N 16D-8N, 18D-6N.

During the 6 weeks that the plants remained in the chambers, the following measurements were recorded: total number of leaves, length and width of every leaf to the nearest 0.1 cm, total plant height to the nearest 0.1 cm (HT), and basal diameter to the nearest 0.1 mm (DIA).

When the plants were harvested at the end of 6 weeks the following measurements were also recorded: leaf dry weight (LFWT), stem dry weight (STMWT), and root dry weight (RTWT). Several additional variables were calculated from these latter three: total plant weight (TOTWT), stem-to-root ratio (SRR), top-to-root ratio (TRR), and leaf, stem, and root weight ratios (LWR, SWR, RWR).

Leaf surface area relations

Many direct measurement methods to obtain leaf surface area are available (Sesták *et al.* 1971). All of them involve destroying the leaves and are tedious and time-consuming. Therefore, we used an indirect method that involved developing regression equations using leaf length (L) and width (W) to predict leaf area (A).

Plants were selected at random to yield a sample of at least 30 leaves for each of the eight clones. All the leaves, both juvenile and expanding, were taken from these plants; the leaf circumferences were then traced on paper. The areas were obtained by using a planimeter that measured to the nearest 0.1 cm². It was assumed for all clones that leaf shape was independent of the environment in which the leaf was grown.

Various models were analyzed using ordinary least squares; the final model chosen was

$$A = a + b(LW) + c(W^2).$$

Parameter estimates and associated statistics were obtained for each clone (table 6). To test the reliability of prediction of the above model, additional data were collected for clones 5321, 5323, 5326, and 5377.

Four statistics were calculated for these four clones using the observed and predicted leaf surface areas (table 7). The predicted areas were obtained by substituting the corresponding values of the independent variables associated with a particular observed area into the correct clonal prediction equation. The statistics were:

$$T_1 = \frac{(\hat{\beta}-\beta_o)'\,X'X\,(\hat{\beta}-\beta_o)}{ks^2} \sim F_{k,n-p}, \text{ where}$$

k = number of parameters in joint null hypothesis under test, and
n = number of observations (Kempthorne 1972)

$$\text{and } T_2 = \frac{1}{4n^2}\left\{\sum_{i=1}^{n} [R(X^{(i)}) - 2i]^2 + \sum_{j=1}^{m} R(Y^{(j)}) - 2j^2\right\};$$

$$T_3 = \sum_{i=1}^{n} (y_i - \hat{y}_i)^2,$$

the sum of squares between observed and predicted leaf areas and

$$T_4 = \sum_{i=1}^{n} |y_i - \hat{y}_i|,$$

the sum of absolute deviations.

Table 6.—*Regression coefficients and associated statistics for eight clones included in Trial II*

Clone	Coefficient	Southeast of coefficient	n	S²	R²
5321	0.50868	0.52286	37	3.184	0.9972
	.54004	.03332			
	.09037	.03587			
5323	.43073	1.05231	40	10.389	.9977
	.52406	.05146			
	.14628	.04666			
5326	– .07917	1.32275	39	14.590	.9953
	.27336	.04602			
	.38605	.04257			
5328	–3.48530	1.15573	36	12.001	.9982
	.64992	.04883			
	.12364	.04511			
5377	1.26054	.64691	50	7.383	.9975
	.29245	.02778			
	.36252	.02795			
5260	– .58338	.73483	50	4.856	.9964
	.63068	.05760			
	.06288	.07197			
5339	.81738	.85277	41	8.087	.9967
	.51805	.04154			
	.21589	.05168			
Balsam	– .06247	.82671	39	6.448	.9945
	.69543	.04729			
	.01553	.08489			

Table 7.—*Several statistics to show the prediction reliability of the leaf area model $Y = a + b(LW) + c(W^2)$ for four clones (Y = leaf area, L = leaf length, W = leaf width)*

Clone	n	T_1	T_2	T_3	T_4	Range of $Y_i - Y_i$
						cm²
5321	2	[1]26.12	[2]0.025	548.63	97.25	– 5.21 to 7.50
5323	25	[1]7.58	[2].020	248.56	63.89	– 6.10 to 3.55
5326	28	[1]10.82	[2].054	1,111.81	125.70	–15.94 to 2.11
5377	26	[1]49.35	[2].067	707.03	112.90	– 8.99 to 1.61

[1] Significant at $P < 0.01$.
[2] Not significant at $P < 0.05$.

The Cramer-von Mises Two-Sample test was used to check

H_o: $F(x) = G(x)$ for all x

vs. H_1: $F(x) \neq G(x)$ for at least one value of x

where $n = m$ = number of observations in each sample,

$F(X^{(i)})$ = the rank of the i-th smallest of the X's in the combined ordered sample, and

$R(Y^{(j)})$ = the rank of the j-th smallest of the Y's in the combined order sample (Conover 1971).

Test statistic T_1 is significant at $\alpha = 0.01$ for all four clones, implying that the joint null hypothesis $\beta = {0 \atop 1}$ is rejected and that the equations do not fit the new data very well. The test statistic T_2 is not significant at $\alpha = 0.10$ for all four clones, implying that the null hypothesis $F(x) = G(x)$ is accepted, and that the equations do fit the new data.

These two statistics give conflicting results, but based on the fact that the leaves of these clones vary somewhat in shape, the estimate, s^2, in the denominator of statistic T_1 may be difficult to estimate. With the exception of clone 5326, the estimated leaf areas were within ±10.0 cm² of the actual leaf areas (table 7). For clone 5326 only five out of the 28 areas calculated exceeded this tolerance. Therefore, the model $Y = a + b(LW) + c(W^2)$ appears satisfactory for estimating leaf surface areas for the four clones (table 7).

In addition to the estimated leaf surface area (LFAREA), we calculated specific leaf area (SLA), leaf weight ratio (LWR), and leaf area ratio (LAR). The relations are:

$$\text{LAR} = \frac{\text{LFAREA}}{\text{TOTWT}} = \frac{\text{LFAREA}}{\text{LFWT}} \times \frac{\text{LFWT}}{\text{TOTWT}}$$

$$= (\text{SLA}) \times (\text{LWR}) \text{ (Sesták } et\ al. \text{ 1971),}$$

where

LFWT = leaf dry weight, and

TOTWT = total plant dry weight.

Vegetative growth

Because the three-factor interaction (photoperiod x temperature x clone) was not significant to the 5 percent level for each of the three vegetative growth variables (DIA, HT, and LFAREA), we considered the mean response of each of the eight clones over levels of photoperiod and temperature for each of these variables (table 8). With a few exceptions, growth in basal stem diameter, height, and leaf area increased rapidly as photoperiod increased from 12 to 16 hours for all eight clones, although not at the same rate for each clone. The increase in growth was less rapid as photoperiod was increased further to 18 hours. Clone 5260 had the greatest height growth rate as photoperiod increased from 16 to 18 hours, and attained the greatest mean height of all eight clones at 18-hour photoperiod.

Balsam poplar exhibited the poorest growth for all three variables (DIA, HT, and LFAREA), while clone 5328 displayed the best growth in diameter and leaf area over all photoperiod levels. Clone 5323 showed the greatest growth in height over all photoperiods.

The effect of temperature on growth in diameter and leaf area was quadratic, in that DIA and LFAREA increased rapidly as the day-night temperature increased from 17-5°C to 29-17°C, then decreased as

Table 8.—*F-values for vegetative growth variables of eight* Populus *clones associated with eight major sources of variation (P = photoperiod, T = temperature, C = clone)*

Source	Dependent variables DIA	HT	LFAREA
Replicate	[1]12.55	[1]9.62	[1]11.56
P	[1]11.65	[1]31.34	[1]17.66
T	[1]29.55	[1]51.08	[1]37.78
P x T	[2]32.35	[3]2.59	[2]2.41
C	[1]24.16	[1]24.51	[1]32.23
P x C	[2]31.06	[1]2.09	[2]1.25
T x C	[2]31.55	[1]2.31	[1]3.30
P x T x C	[2]31.21	[2]1.22	[2]1.00

[1] Significant at $P < 0.01$.
[2] Not significant at $P < 0.05$.
[3] Significant at $P < 0.05$.

the day-night temperature was further increased to 35-23°C. This trend was not so obvious for height growth. Generally, height growth levelled off as the day-night temperature increased from 29-17°C to 35-23°C for all eight clones, although there were some exceptions. The rate of growth over temperature levels was not the same for each clone.

All main effects—experiment, photoperiod, temperature, and clone—were significant at the 1 percent level for all three growth variables; the temperature x clone interaction was significant for the variables HT and LFAREA, and the photoperiod x clone interaction was significant for variable HT (table 6). This meant that the clones responded significantly differently over temperature levels for the variables HT and LFAREA and for HT over photoperiod levels.

Dry weight

Again, the three-factor interaction, photoperiod x temperature x clone, was not significant at the 5 percent level for each of the four dry weight variables LFWT, STMWT, RTWT, and TOTWT (table 9). With the exception of clone 5339 and balsam poplar, dry weights of leaves, stem, and total plant increased rapidly with increase in photoperiod from 12 to 16 hours and less rapidly from 16 to 18 hours, although not at the same rate for each clone.

Balsam poplar yielded the lowest dry weight accumulation with respect to leaves, stem, roots, and total plant, while clones 5328 and 5323 yielded the highest dry weight production for all the dry weight variables except STMWT over all photoperiod levels. Clones 5377 and 5326 produced the highest STMWT in all photoperiods except for 18 hours.

Table 9.—*F-values for dry weight variables of eight* Populus *clones associated with eight major sources of variation*

	Dependent variables			
Source	LFWT	STMWT	RTWT	TOTWT
Replicate	[1]5.96	[2]9.39	[1]6.01	[1]7.91
P	[2]9.91	[2]13.30	[3]0.97	[2]6.61
T	[2]26.98	[2]22.16	[2]15.78	[2]25.96
P x T	[3]1.69	[3]1.60	[3]0.89	[3]1.37
C	[2]25.82	[2]13.80	[2]22.04	[2]20.73
P x C	[3]1.00	[3]1.36	[3]0.62	[3]0.94
T x C	[2]2.60	[1]1.66	[1]1.67	[2]2.06
P x T x C	[3]0.91	[3]1.08	[3]1.01	[3]0.96

[1]Significant at $P < 0.05$.
[2]Significant at $P < 0.01$.
[3]Not significant at $P < 0.05$.

The dry weight of leaves, stem, and roots increased sharply as the day-night temperature increased from 17-5°C to 29-17°C, and decreased as the temperature increased from 29-17°C to 35-23°C. The classic quadratic response to temperature was exhibited by all eight clones.

The photoperiod, temperature, and clone sources of variation were all significant at the 1 percent level for all four dry weight variables, with the exception of the photoperiod source of variation for RTWT. The effect of photoperiod on RTWT was not even significant at the 10 percent level (table 9).

The temperature x clone interaction was significant at the 1 percent level for LFWT and TOTWT and at the 5 percent level for STMWT and RTWT. This indicated that the response of each clone over temperature was significantly different, one from another. In fact, the differential response of clones over temperature with respect to LFWT was much more pronounced than the responses with respect to either STMWT or RTWT.

The effect of the experiment was significant at the 1 percent level for STMWT only and significant at the 5 percent level for the other dry weight variables. This may indicate that stem dry weight production was altered to a greater degree than either leaf or root dry weight production by the change in "soil" composition from Experiment 1 to Experiment 2.

Distribution of assimilate

The distribution of assimilate was expressed in dry stem weight-to-root weight and top-to-root ratios as well as leaf, stem, and root dry weights as proportions of total dry weight. With the exception of SWR, the photoperiod x temperature x clone interaction again was not significant at the 5 percent level for all the other assimilate distribution variables (table 10).

The SRR and TRR increased rapidly as photoperiod increased from 12 to 16 hours for all clones with the exception of balsam poplar. As photoperiod continued to increase from 16 to 18 hours, clones 5260, 5339, and balsam poplar continued to increase in SRR and TRR at a high rate. Clones 5377, 5323, and 5328 continued to increase at a low rate and clones 5321 and 5326 decreased in SRR and TRR (fig. 2).

As the day-night temperature increased from 17-5°C to 35-23°C, most of the clones increased rapidly in SRR and TRR.

Table 10.—*F-values for assimilate distribution variables of eight* Populus *clones associated with eight major sources of variation (P = photoperiod, T = temperature, C = clone)*

	Dependent variables				
Source	**SRR**	**TRR**	**LWR[1]**	**SWR[1]**	**RWR[1]**
Replicate	[2]2.81	[2]0.13	[2]0.80	[3]9.98	[2]0.78
P	[3]33.27	[3]20.53	[4]3.66	[3]29.15	[3]22.65
T	[3]30.73	[3]16.11	[2]0.91	[3]31.24	[3]13.19
P x T	[2]1.67	[2]0.72	[2]1.89	[2]2.44	[2]1.18
C	[3]22.43	[3]29.49	[3]59.18	[3]38.73	[3]26.72
P x C	[3]2.13	[2]1.46	[3]2.26	[3]2.39	[3]3.74
T x C	[4]1.74	[3]2.62	[2]1.62	[2]0.96	[3]2.49
P x T x C	[2]1.31	[2]0.97	[2]1.03	[4]1.61	[2]1.06

[1] These proportions were transformed by the function arcs in $\sqrt{P}$. The analyses of variance were performed on these transformed variables.
[2] Not significant at $P < 0.05$.
[3] Significant at $P < 0.01$.
[4] Significant at $P < 0.05$.

The main effects—photoperiod, temperature, an clone—were significant at the 1 percent level excep for the variable LWR. Here the photoperiod effec was only significant at the 5 percent level and th temperature effect was not significant at all. Poss bly photoperiod affects LWR more than temperature

The effect of the experiment was not significan at the 5 percent level for any of the assimilate distribution variables except SWR, for which it wa highly significant at the 1 percent level.

The photoperiod x clone interaction was signif cant at the 1 percent level for all the variables excep TRR. For this variable the above interaction was no significant at the 5 percent level. This implied tha there was no significant difference in response wit respect to TRR from one clone to another over level of photoperiod. Similarly, the temperature x clon interaction was significant at the 1 percent level fo

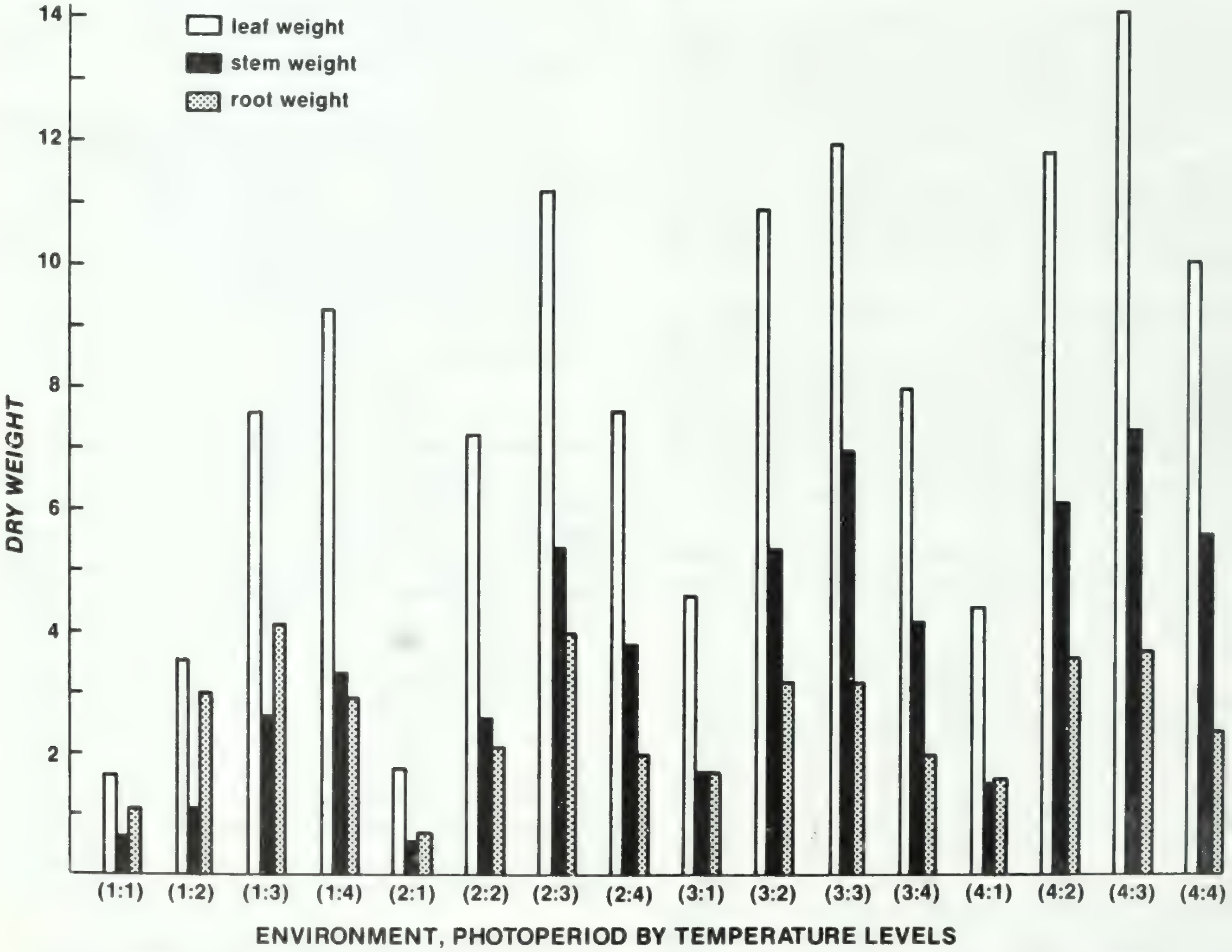

Figure 2.—*Average dry weight distribution over all clones in each of 16 environments (numbers in parentheses along the x-axis represent photoperiod and temperature levels, respectively).*

TRR and RWR, at the 5 percent level for SRR, and not significant at the 5 percent level for LWR and SWR. The response of RWR from one clone to another, therefore, was significantly different over temperature, but the responses of LWR and SWR were not.

The combined action of photoperiod and temperature produced noticeable shifts in the average dry weight distribution of all eight clones combined (fig. 2), even though the photoperiod x clone interaction for LWR, SWR, and RWR was not significant at the 5 percent level (table 10).

Relative size of assimilatory apparatus

The photoperiod x temperature x clone interaction was not significant at the 5 percent level, so we considered leaf area ratio (LAR) and specific leaf area (SLA) versus levels of photoperiod and temperature separately for all eight clones (table 11).

Generally, the relative size of the leaves on a square decimeter per gram basis yields information about leaf density. The magnitude of the variables SLA (=LFAREA/LFWT) and LAR (=LFAREA/TOTWT) indicates the degree to which assimilation rate and efficiency are affected by changes in photoperiod and temperature.

SLA was definitely more sensitive to changes in environment than LAR. The former varied from 1.6 to 2.6 and the latter from 0.8 to 1.5. Clone 5339 had the densest leaves (large SLA) and balsam poplar had the least dense leaves (small SLA) over all temperature levels.

Table 11.—*F-values for relative leaf size variables of eight* Populus *clones associated with eight major sources of variation (P = photoperiod, T = temperature, C = clone)*

	Dependent variable	
Source	**LAR**	**SLA**
Replicate	[1]0.88	[1]3.90
P	[2]10.69	[2]7.74
T	[2]14.12	[2]17.16
PxT	[1].57	[1]1.40
C	[2]8.46	[2]20.24
PxC	[1]1.23	[1]1.40
TxC	[1]1.39	[1]1.23
PxTxC	[1].82	[1]1.02

[1] Not significant at $P < 0.05$.
[2] Significant at $P < 0.01$.

Only the main effects—photoperiod, temperature, and clone source—were significant at the 1 percent level. The remaining sources were not significant at the 5 percent level (table 10).

Except for clone 5260, which decreased sharply, all clones increased in SLA and LAR as photoperiod increased from 16 to 18 hours. As temperature increased, LAR and SLA generally increased for all clones; no quadratic response was observed. With the exception of clones 5323 and 5377, all clones increased rapidly in SLA at first, then moderately, and finally very sharply as the day-night temperature increased from 17-5°C to 35-23°C.

Selection Indices

Selection indices have been used for selection in animal and plant breeding programs when several quantitative characters are considered (Elston 1963, Hazel 1943, Hazel and Lush 1942, Kempthorne and Nordskog 1959, Panse 1946, Smith 1936, and Tallis 1962). Hanson and Johnson (1957) have discussed methods for calculating a general selection index based on pooled information from two or more experiments. Their index was similar to our index I_1, which is discussed below. Two data sets were combined to minimize sampling errors and to improve the estimation of the genotype by environment interaction. The two combined populations were grown under identical environments. In this manner a selection index determined from one data source could be used successfully as a general index. The expected genetic advance was used as a means of index reliability.

Okuna *et al.* (1971) evaluated the performance of 29 rice varieties grown in several environments using seven different methods, and one of the methods they used involved principal component analysis.

A selection index often considered appropriate is a function of the form:

$$I = w_1x_1 + w_2x_2 + \dots + w_px_p;\ i = 1, \dots p,$$

where:

w_i = i-th known or unknown economic weight, and

x_i = i-th measured trait (Hazel 1943, Smith 1936). However, such a linear function may not be appropriate, or, if the economic weights are unknown, the experimenter may not want to go through the involved estimation procedure necessary. The researcher may not even want to consider any weights.

An alternative is to consider a nonlinear function of the form

$I = (w_1x_1)(w_2x_2) \ldots (w_px_p) = w'x_1x_2 \ldots x_p$. For simplicity, suppose $p = 2$ so that only two traits are being considered. Then figure 3 illustrates selection on the basis of a linear index, $x_1 + wx_2$, and figure 4 illustrates selection on the basis of a nonlinear index, wx_1x_2. In both cases, the shaded area represents the specified fraction, λ, of the individuals to be selected from the known population. This fraction is obtained by assigning ranks within the group of clonal values for each index and selecting the clones with highest rank from each group. This way the selection ability of each index can be compared with that of another.

In addition to linear or nonlinear indices of the forms mentioned above, the literature suggests a variety of approaches to the problem of discriminating among individuals on the basis of several traits. These are discussed below, together with our own further development of some of them.

H-S index.—Consider the index (in matrix notation) of the form

$H = a'X$,

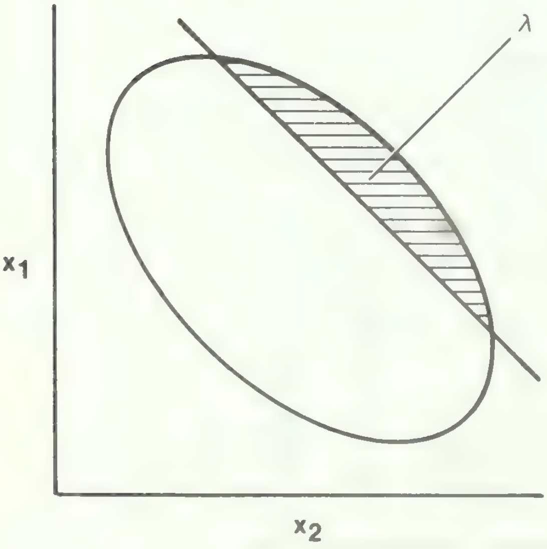

Figure 3.—*Selection based on the linear index $x_1 + wx_2$ for the selection portion (λ) of the population.*

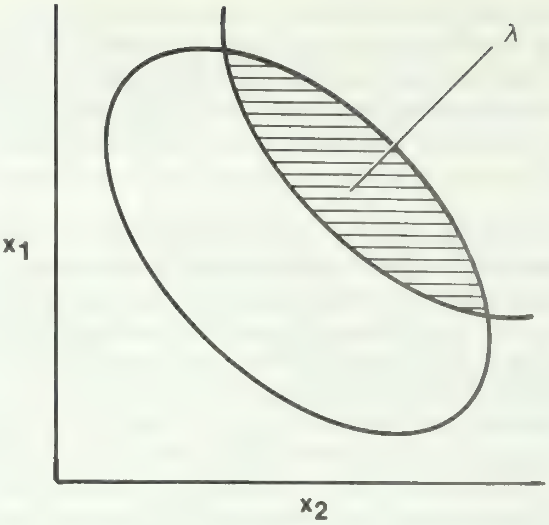

Figure 4.—*Selection based on the nonlinear index wx_1x_2 for the selection portion (λ) of the population.*

where

a = vector of known economic weights, and

X = vector (mxl) of unknown genotypic values of the individual clone for the m attributes of interest on which selection is to be based.

Because index H cannot be easily estimated, let selection be based on a linear function, I, which correlates best with the index H of the form

$I_1 = b'Y$,

where

Y = vector (mxl) of phenotypic values of the individual clone for the m attributes of interest on which selection is to be based, and
b = vector of coefficients to be determined from the system $Pb = Ga$ (Hazel 1943, Smith 1936), and where

P = matrix of phenotypic variances and covariances,

G = matrix of genotypic variances and covariances, and
a = vector of previously defined constants.

This implies $b = P^{-1}Ga$ and $I_1 = (P^{-1}Ga)'Y$.

Provided the following conditions hold, the selection index, I_1, will be a correct predictor of superior growth potential:

(1) The phenotypic value, P_i, for the i-th trait of an individual clone will be made up of the sum of two parts, the genotypic value, G_i, defined as the average of the phenotypic values possible over a range of environments and the environmental contribution, E_i—i.e., $P_i = G_i + E_i$. The $\mathrm{Cov}(G_iE_i) = 0$, but genotypic by environment interactions, $(GE)_i$, can be presented provided genotypes and environments are associated with each other at random and $(GE)_i$ is incorporated with E_i.

(2) The genetic value, G_i, is composed entirely of additive gene effects.

(3) The quantities Y_i and H are such that the regression of H on any linear function of the Y_i is linear (Kempthorne and Nordskog 1959).

(4) The matrices of variances and covariances P and G are known.

Weight-free index.—Elston (1963) suggested the following nonlinear index for selection with respect to p traits at a time:

$$I_2 = \prod_{i=1}^{p} (x_i - k_i)$$

where

x_i = i-th trait measured on a particular individual clone, and
k_i = greatest lower bound of the x_i for all the individuals under consideration for selection.

However, this index is not independent of the scales used to measure the x_i's, thus:

$$x_i' = \log_{10}(x_i - k_i),$$

and the index becomes

$$\sum_{i=1}^{p} x_i'$$

If the index is to be based on weighted measurements, $w_1x_1, w_2x_2, \ldots, w_px_p$, and the w_i's are unknown, then an index that is invariant under the choice of the w_i's should be used. The index becomes:

$$I_2' = \prod_{i=1}^{p} (x_i' - k_i'),$$

where

$x_i' = \log_{10}(x_i - k_i)$, and
K_i' = lower bound of x_i'.

The index I_2 was evaluated for each clone within each environment and, since environments were assumed independent of each other, a simple average value for each clone over all environments was calculated.

Adaptation index.—Finlay and Wilkinson (1963) proposed a method of analyzing the adaptation of a randomly chosen group of 277 varieties of barley from a world collection, grown in replicated trials for several seasons at three sites in South Australia. For each variety, they computed a linear regression of individual grain yield on mean grain yield over all varieties for each environment (site and season). A slope of 1.00 meant that the variety was well adapted to all environments. This regression coefficient was then a measure of variety adaptation. The authors transformed their data logarithmically to index independence between means and their variances.

The study was assisted by the use of a scatter diagram that plotted variety regression coefficients (slopes) against variety means. However, no attempts were made by the authors to select a fraction, λ, of the varieties showing superior growth potential with respect to yield over all environments. We propose to go a step further than Finlay and Wilkinson and create the following index:

where $I_3 = (\hat{\mu}_{i.} - k_1)(b_i - 1.0)^2 - k_2$,

$\hat{\mu}_{i.}$ = mean of i-th variety over all environments for a particular variate of interest on which selection is to be based, and

b_i = regression coefficient (slope) of Y_{ij} on $\hat{\mu}_{.j}$,

where

Y_{ij} = mean of i-th variety at the j-th environment,
$\hat{\mu}_{.j}$ = mean of j-th environment over all varieties,
k_1 = greatest lower bound of $\hat{\mu}_{i.}$ and
k_2 = greatest lower bound of $(b_i - 1.0)^2$.

The index I_3 was evaluated for each clone for each of several variates of interest.

An alternative approach was to consider a canonical variable (Morrison 1967)—which is a linear combination of all the variates of interest in the selection process—as a variate on which selection is to be based. New environment and variety of environment means were found and the coefficients $b_i^{(\vartheta)}$ were obtained by linear regression techniques.

Then the index:

$$I_3^{(\vartheta)} = (\hat{\mu}_{i.}^{(\vartheta)} - k_1)\,(b_i^{(\vartheta)} - 1.0)^2 - k_2 \qquad (6)$$

was calculated for each clone, where the superscript ϑ stands for the ϑ-th canonical variable used to evaluate the above previously defined parameters.

Curvature index.—Wu (1973) proposed that if the response of a varietyto various environments is quadratic, that is:

$$Y_i = a + bx_i + cx_i^2,\ i = 1,m,$$

where

m = number of environments,
Y_i = observed response of a clone at the i-th environment, and
x_i = independent i-th environmental measure,

then a measure of plant stability is the reciprocal of the radius of curvature as expressed below:

$$\rho = \left|\frac{1 + (y')2^{3/2}}{y''}\right|, \text{ and}$$

$$y' = b + 2cx = r, \text{ and}$$

$$y'' = 2c. \text{ Hence,}$$

$$\rho^{-1} = \left|\frac{1 + (b + 2cx)^{2^{3/2}}}{2c}\right|^{-1},$$

where x is day temperature and is evaluated at $\bar{x}$, and b anc c are coefficients. (A curvature of nearly zero implied the curve was nearly linear and clonal response to various environments was stable.) Next consider the index:

$$I_4 = (\bar{y}_i - k_1)\,(k_2 - |\rho^{-1} - (\bar{\rho})^{-1}|),$$

where

$\bar{y}_i$ = i-th clonal mean over all environments for a particular trait,
ρ^{-1} = curvature of the i-th clone,
$(\bar{\rho})^{-1}$ = average curvature over all clones,
k_1 = greatest lower bound of y_i, and
k_2 = greatest lower bound of $|\rho^{-1} - (\bar{\rho})^{-1}|$

However, this index deals with only one trait at a time, so consider the index:

$$I_4^{(\vartheta)} = (\bar{y}_i^{(\vartheta)} - k_1)\,k_2 - |\rho_\vartheta^{-1} - (\bar{\rho})_\vartheta^{-1}|,$$

where

$\bar{y}_i^{(\vartheta)}$ = i-th clonal mean of the ϑ-th canonical variable associated with the clone source of variation in the MANOVA,
ρ_ϑ^{-1} = curvature of the i-th clone based on ϑ-th canonical variable,
$(\bar{\rho})_\vartheta^{-1}$ = average curvature over all clones based on ϑ-th canonical variable,
k_1 = greatest lower bound of $\bar{y}_i^{(\vartheta)}$, and
k_2 = greatest lower bound of $|\rho_\vartheta^{-1} - (\bar{\rho})_\vartheta^{-1}|$.

With this index, clones with curvature near the average will be preferred over those with curvature far from the average.

Hamiltonian index.—Wu (1973) also considered the function $H = f(y,r)$, where $y = g(x)$ and $r = h(x)$. Here y and r are total growth and growth rate of the clones or varieties over various environments. The function, H, is the Hamiltonian for the system represented by the equations:

$$y' = b + 2cx = r,$$
$$y'' = 2c$$

(Brauer and Nohel 1969). If the above system is written in the form:

$$\frac{dy}{dx} = y' = \frac{\partial H}{\partial r},$$

$$\frac{dr}{dx} = y'' = -\frac{\partial H}{\partial y}.$$

With H defined as the total energy of the system and, assuming the principle of conservation of energy, the function H is a constant for different values of x. Therefore:

$$\frac{dH}{dx} = 0, \text{ and}$$

using one of the chain rules of calculus

$$\frac{dH}{dx} = \frac{\partial H}{\partial y}\frac{dy}{dx} + \frac{\partial H}{\partial r}\frac{dr}{dx}$$

which leads to the system derived previously:

$$\frac{dy}{dx} = y' = \frac{\partial H}{\partial r}$$

$$\frac{dr}{dx} = y'' = \frac{\partial H}{\partial y}$$

Substituting values for y' and y" the system (Equation 10) becomes:

$$\frac{\partial H}{\partial r} = r$$

$$\frac{\partial H}{\partial y} = -2c.$$

The solutions of this system of equations are $H = r^2/2 + c_1$ and $H = -2cy + c_2$, where c_1 and c_2 are constants. Since a linear combination of these two solutions is also a solution to the system,

$$H = \frac{r^2}{2} - 2cy$$

is also a solution; substituting for y and r produces

$$H = \frac{1}{2}b^2 - 2ac,$$

where a, b, and c are coefficients. Similar to the curvature index, consider

$$I_5^{(\vartheta)} = (\bar{y}_i^{(\vartheta)} - k_1)(k_2 - |H_\vartheta - \bar{H}_\vartheta|), \qquad (11)$$

where $y_i^{(\vartheta)}$ and k_1 are defined as the index $I_4^{(\vartheta)}$ and

H_ϑ = Hamiltonian of i-th clone based on ϑ-th canonical variable,
$\bar{H}_\vartheta$ = average Hamiltonian over all clones based on ϑ-th canonical variable, and

k_2 = greatest lower bound of $|H_\vartheta - \bar{H}_\vartheta|$.

Again, clones with a Hamiltonian, H close to $\bar{H}$, will be preferred.

Distance index.—The first step in this procedure is to calculate all the possible pairwise squared generalized distances between the clones of interest using a pooled variance-covariance matrix whose rank equals the number of variates used as discriminators. Then

$$D^2(i|j) = (\bar{x}_i - \bar{x}_j)' \, \mathrm{Cov}^{-1}(\bar{x}_i - \bar{x}_j),$$

where

$\bar{x}_i - \bar{x}_j$ = a vector (s x 1) of clonal mean differences,
Cov = pooled variance-covariance matrix (s x s), and
s = number of variates used as discriminators.

Next, these distances are used to cluster the clones into subgroups which are more homogeneous than those determined by the unweighted pair group method; the results are then displayed as a dendrograph (McCammon and Wenninger 1970). The dendrograph is looked at subjectively to determine which clones demonstrate superior growth.

Canonical index.—A canonical analysis is performed on the combined data over all environments for the variates (dependent variables) on which selection is to be based. Canonical variables of the form

$$Y^{9(\vartheta)} = R'_{\vartheta} X$$

are formed

where

$\vartheta = 1, \ldots, s$,
s = number of variates considered in the analysis,
X = a vector of correlated dependent variables on which selection is to be based, and
R_ϑ = ϑ-th normalized characteristic vector of $E^{-1}H$

where

$R'_\vartheta E R_\vartheta = 1$ (a scalar),
E = pooled error matrix, and
H = partial sums of squares and cross products matrix due to clone by environment source of variation in the Multivariate Analysis of Variance (MANOVA) table.

Means of the canonical variables are obtained by replacing the vector X by $\bar{X}$ such that

$$\bar{Y}_{ij}^{(\vartheta)} = R'_\vartheta \bar{X}_{ij}$$

where

$i = 1, \ldots, p$,
$j = 1, \ldots, m$,
p = number of clones,
m = number of environments, and
x_{ij} = a vector of means (s x 1) for the i-th clone at the j-th environment.

Then $\bar{Y}^{(2)}$ is plotted against $\bar{Y}^{(3)}$ and the resultant plot viewed subjectively. One looks for the clones in each environment that consistently are farthest from the origin. These are the superior clones.

Difficulties

As stated earlier, the H-S index is a correct predictor of superior growth potential only if **all** the mentioned assumptions hold. Immediately one observes that the variance-covariance matrices, P and

G, are now known and that only estimates of these are available. Data are often insufficient to estimate G. So the index is subject to sampling and estimation errors. Also the assumption that $P_i = G_i + E_i$ is usually unrealistic and Cov $(G_iE_i \neq 0)$. This would change the estimation procedure for obtaining the vector of coefficients, b. There also exists the problem of assigning the proper weight to each trait in the index.

It should be noted that even if some of the weights in the original index, H, are zero, all of the coefficients estimated for I_1 will be **nonzero.**

The weight-free index, contrary to its name, is really an index which assigns equal weights to all variates or traits. This may not be desirable, since one may want to select a small fraction of individuals on the basis of several traits that are to be unequally emphasized. This index also selects individuals with larger measurements on each trait, so one must arrange to measure each trait on a scale that will meet this criterion. Thus, if there is a trait for which a smaller measurement is desired, one would change the direction of the scale on which the trait is measured.

The distributions of the measurements on each of the traits should be as similar as possible for the weight-free index to be reliable. Frequently, when histograms are drawn up for the various traits contained in the index, the distributions of the measurements on some of the traits are of an entirely different type—e.g., bimodal instead of unimodal—from those of others. Those measurements should be transformed to lessen the differences.

The adaptation index seems the most promising, although index I_3 selects individuals on the basis of only one trait at a time. One must either look at each group of clonal values for index I_3 for each trait of interest in the selection process separately, remembering that these traits are highly correlated with each other, or use index $I_3^{(3)}$. With this index, however, it is difficult to know which canonical variable to use.

The curvature index, like the adaptation index, selects individuals based on only one trait at a time. It also requires an independent variable with at least three levels to fit the assumed quadratic. The radius of curvature of this function varies with different values of the independent variable (some environmental measure). For comparison, index I_4 is evaluated at the mean of the independent variable, but this may not be appropriate.

The Hamiltonian index comes from a principle of motion in physics which states that the total energy of a system is equal to the sum of the potential and kinetic energy. Applying this idea to biology involves substituting growth and growth rate for potential and kinetic energy. The index I_5 represents the biological total energy of the system. The principle of conservation of energy is assumed so that along any solution of a Hamiltonian system the total energy is constant. This may not be true when one considers growth and growth rate of a plant as position and speed of a particle.

The problem with the distance index is that it involves a subjective instead of objective procedure. Certain clones will be segregated from the main group but it will not be clear from the dendrograph whether these segregated clones are superior or inferior. Additional prior information is needed to interpret the results correctly.

The canonical index again is a subjective procedure, but seems to hold great promise, especially if $Y^{(2)}$ and $Y^{(3)}$ are plotted against each other instead of $Y^{(1)}$ and $Y^{(2)}$. This procedure appears to work best when the number of clones is greater than the number of environments.

Reliability of indices

To make reliability statements (such as confidence intervals) about the various indices, their probability density functions (p.d.f.'s) or distributions must be known exactly or approximated by some known tabulated distributions. An alternative is to assume some limiting distributions.

For the H-S index, I_1, one could easily find the expected value of I_1, $E(I_1)$, and the variance of I_1, $(V(I_1)$, if the P and G matrices were known. Then, if one assumed that the phenotypic values, Y, were distributed normally with some finite mean and variance, the distribution of index I_1 could be found. But matrices P and G must be estimated because they are usually not known. This makes it extremely difficult to find the variance of I_1.

On the other hand, the p.d.f. for the weight-free index, I_2, and adaptation index, I_3, can be found, but only under very restricted conditions. Without these restrictions some limiting distributions must be assumed.

For example, let selection be based on two traits only $(p = 2)$ and assume x_1 and x_2, the two traits, are distributed lognormal with means, μ_1 and μ_2 and variances, σ_1^2 and σ_2^2, respectively. Then if one imposes the restrictions $k_1 = k_2 = 0$ (lower bound for x_1 and x_2 is zero) and x_1 and x_2 independent, then the index $I_2 = t = x_1x_2$ has the following p.d.f.:

$$g(t) = \frac{1}{\sqrt{2\pi}\, t\, \sqrt{\sigma_1^2 + \sigma_2^2}}\, e^{\,1/2\{\log t \quad (\mu_1 + \mu_2)\}^2/(\sigma_1^2 + \mu_2^2)},\ 0 < t < \infty.$$

If ${}_1 = {}_2 = 0$ and ${}_1^2 = {}_2^2 = 1$ then the above p.d.f. becomes

$$g(t) = \frac{1}{2t\sqrt{\pi}}\, e^{-1/4(\log t)^2},\ 0 < t < \infty.$$

If $k_1 / k_2 / 0$ then the p.d.f. cannot be found analytically. Note that the restriction x_1 and x_2 independent has not been relaxed, which is the case with this study.

The next step would be to find the first and second moments of indices I_2 and I_3, assuming the traits on which selection was to be based are normally distributed with finite mean and variance. Then Monte Carlo techniques could be used to artificially construct indices I_2 and I_3 based on sampling procedures, and frequency curves could be drawn. Next, known distributions such as t or F would be used to approximate the p.d.f.'s of index I_2 and I_3 based on the previously calculated moments, and frequency curves would again be drawn. Goodness-of-fit tests could then be used to determine how well the known distributions approximate the sample-based p.d.f.'s of indices I_2 and I_3.

The simplest method is as follows: Deming (1943) stated that the variance of a function g of a number of correlated random variables $x_1, \ldots, x_n$ could be approximated by the expression

$$V(g) \approx \sum_{i=1}^{n} \sum_{j=1}^{n} \left|\frac{\partial g}{\partial x_i}\right| \left|\frac{\partial g}{\partial x_j}\right| \operatorname{Cov}(x_i x_j).$$

Now recall the Central Limit Theorem (Hogg and Craig 1969), which states that if $x_1, \ldots, x_n$ denote the items of a random sample of size n from any distribution having finite variance σ^2, then the random variable $\sqrt{n}\,(\bar{x} - \mu)/\sigma$ has a limiting normal distribution with zero mean and unit variance. Utilizing this fact, assume the expression

$$\frac{\hat{I}_\vartheta - I_\vartheta}{(I_\vartheta)} \sim N(0,1) \text{ as } n \to \infty$$

$$\vartheta = 2,3;$$

then confidence intervals can be constructed of the form

$\text{Prob}\,(L < I_\vartheta < u) \geqslant 1 - \alpha \quad \vartheta = 2,3,$
where

L = some lower limit,

u = some upper limit,

$1-\alpha$ = confidence coefficient, and

α = significance level.

Likewise, the variances of indices I_4 and I_5 can also be found. It should be noted that a given index is more reliable if it fails to select a superior clone than if it includes a bad clone.

Evaluation of indices

Data collected by Wray (1974) (Trial I) were used to evaluate the seven indices described on the preceding pages. One growth chamber and two greenhouse environments were utilized to assess the juvenile growth potential of 25 *Populus* clones. There were four replications in each environment, yielding 300 observations. The variables measured were total plant height (HT), and stem and leaf dry weights (STMWT and LFWT).

Data from Trial II were also used to evaluate seven of the selection indices. Eight clones were grown twice in 16 environments, yielding 256 observations. Six variables were measured: basal diameter (DIA), total plant height (HT), leaf surface area (LFAREA), and leaf, stem, and root dry weights (LFWT, STMWT, RTWT).

H-S index.—Before estimating the coefficients of this index, the P and G matrices had to be obtained. The elements of these variance-covariance matrices were procured by performing all possible analyses of variance (ANOVA) and cross-product analyses for the traits of interest (three traits for Trial I and six traits for Trial II). Assuming all factors as random, except replicates within environments for Trial I, the expected mean squares were determined.

Assuming the model

$$P = G + E + EG$$

and $\quad \sigma_P^2 = \sigma_G^2 + \sigma_E^2 + \sigma_{EG}^2$

where

P = phenotypic value,
G = genotypic value,
E = environment component,
EG = genotype by environment interaction component,
σ^2_P = phenotypic variance,
σ^2_G = genotypic variance,
σ^2_E = environmental variance, and
σ^2_{EG} = genotype by environment variance,

the component of variance estimates, $\hat{G}_{ij}$ and $\hat{P}_{i,j}$, were obtained (table 12).

Elements of the vector, α, of economic weights were set equal to 1. Coefficients for index I_1 associated with each trait were obtained for the original data and the data transformed by means of logarithms to the base ten.

From the signs and magnitudes of the coefficients, index I_1 appeared to be a contrast between LFWT and STMWT in Trial I (table 13). For Trial II, however, index I_1 appeared to be a comparison of LFWT and STMWT versus RTWT and LFAREA, and DIA, HT and RTWT versus STMWT and LFAREA for the original and transformed data, respectively (table 13).

Index I_1 was evaluated by environment for Trial I for both the original and transformed data. Ranks were assigned to the index values within each group. The ranking of the clones within each environment varied substantially from one environment to another for both the original and transformed data (table 14). However, within each environment the ranks were approximately the same for both the original and transformed data. Since the three environments were independent of each other, these index values were summed for each clone and ranks were assigned to these values for both the original and transformed data.

Table 12.—*Formulas to obtain component of variance estimates for each trial*

Component[1]	Trial I	Trial II
$\hat{G}_{ij} = \sigma_{C_{ij}}$	$\dfrac{\text{M.S. (Clone)}_{ij} - \text{M.S. (E x C)}_{ij}}{12}$	$\dfrac{\text{M.S. (Clone)}_{ij} - \text{M.S. (E x C)}_{ij}}{32}$
$\hat{\sigma}^2_{EG_{ij}} = \hat{\sigma}^2_{EC_{ij}}$	$\dfrac{\text{M.S. (E x C)}_{ij} - \text{M.S. (Error)}_{ij}}{4}$	$\dfrac{\text{M.S. (E x C)}_{ij} - \text{M.S. (Error (b))}_{ij}}{2}$
$\sigma^2_{E_{ij}}$	$\dfrac{\text{M.S. (Envir)}_{ij} - \text{M.S. (E x C)}_{ij}}{100}$	$\{\text{M.S. (Envir)}_{ij} - \text{M.S. (Error (a))}_{ij} - \text{M.S. (E x C)}_{ij} + \text{M.S. (Error (b))}_{ij}\}/16$
	for i,j = 1,2,3 (number of variables)	for i,j = 1, . . . , 6 (number of variables)

[1] The three components listed were used to obtain the quantity:

$$\hat{P}_{ij} = \hat{\sigma}^2_{C_{ij}} + \hat{\sigma}^2_{EC_{ij}} + \hat{\sigma}^2_{E_{ij}}$$

Table 13.—*Estimated coefficients for index I_1 associated with various traits by data base and trial*

Trait	Trial I		Trial II	
	Data base		Data base	
	Original	Transformed	Original	Transformed
DIA	—	—	6.8974	27.4666
HT	0.3137	0.6631	1.0832	9.8186
LFWT	2.1883	1.9500	118.9613	1.9062
STMWT	−3.3192	−1.1332	66.0984	−4.4460
RTWT	—	—	−35.5430	8.0979
LFAREA	—	—	−61.9364	−15.7343

Index I_1 was not evaluated for each environment in Trial II because the main objective was to select

Table 14.—*Ranks associated with index I_1 values by environment for both the original and transformed data in Trial I*

Clone	Environment					
	1		2		3	
	O[1]	T[2]	O	T	O	T
4877	11	12	20	22	14	15
4878	16	19	10	14	8	11
4879	19	22	8	7	18	12
5258	5	5	18	8	22	9
5262	13	20	6	10	9	10
5263	10	14	13	20	16	20
5264	4	3	5	5	4	4
5265	2	2	3	2	1	2
5266	1	1	1	1	3	3
5267	22	17	22	24	17	21
5271	25	25	25	25	23	25
5272	9	8	15	16	13	17
5321	20	18	17	18	21	24
5322	24	24	14	11	5	8
5323	7	7	7	6	6	5
5324	17	15	19	13	15	18
5325	6	6	9	9	10	7
5326	8	11	21	15	24	13
5327	14	13	11	17	11	14
5328	21	9	4	4	7	6
5331	15	16	12	12	12	19
5332	18	21	16	19	19	22
5334	3	4	2	3	2	1
5260	23	23	24	23	20	23
5377	12	10	23	21	25	16

[1] Original data.
[2] Transformed data.

clones exhibiting rapid juvenile growth over all 16 environments. Marked variation in the ranking of the clones was found from one environment to the next.

For Trial I, clones 5266, 5334, 5265, 5264, and 5323 were selected when the original data were considered, and clones 5266, 5265, 5334, 5264, and 5328 when the transformed data were used (table 15). This selection was based on the assumption that the top 20 percent of the clones under consideration was to be chosen. Essentially the same clones were chosen, regardless of the data base (original or transformed). The data, therefore, need not have been transformed from a selection viewpoint.

In Trial II, clone 5323, balsam poplar, and clones 5339 and 5321 were selected based on the original and transformed data, respectively (table 16). The results of this index are unexpected, since clone 5339 and balsam poplar are definitely not superior.

Table 15.—*Ranks associated with the values of five different indices in Trial I*

Clone	Index								
	1		2	3				6	7
	0[1]	T[2]	0	TLF[4]	TST[5]	THT[6]	OC[7]	0	0
4877	14	19	17	18	19	18	14		
4878	9	13	18	16	17	13	6		
4879	18	12	5	8	4	3	13	7	
5258	17	7	3	2	1	8	23	9	
5262	6	9	11	11	6	1	2		4
5263	13	20	15	15	10	2	7		5
5264	4	4	8	9	16	14	5	4	
5265	3	2	6	3	9	16	11	3	3
5266	1	1	2	1	3	4	1	1	1
5267	22	22	24	21	23	21	17		
5271	25	25	25	24	24	22	25		
5272	11	11	14	12	13	6	8		
5321	20	21	23	23	21	20	18		
5322	15	15	13	25	22	23	21		
5323	5	6	10	6	8	9	3	10	
5324	16	16	16	13	14	19	15		
5325	7	8	9	5	7	7	4		
5326	21	10	4	4	2	10	22	5	
5327	10	14	20	14	18	17	9		
5328	8	5	12	10	20	24	16		
5331	12	17	19	17	11	12	10		
5332	19	23	22	20	12	5	12		
5334	2	3	1	19	15	15	19	2	2
5260	24	24	21	22	25	25	20	8	
5377	23	18	7	7	5	11	24	6	

[1] Original data based on three traits.
[2] Transformed data based on three traits.
[3] Original data based on two traits.
[4] Transformed data based on LFWT.
[5] Transformed data based on STMWT.
[6] Transformed data based on HT.
[7] Original data utilizing a canonical variable.

Table 16.—*Ranks associated with the values of seven different indices in Trial II*

Clone	Index								
	1		2	3	4	5	6	7	
	0[1]	T[2]	0	OC[3]	OC	OC	0	OC1[4]	OC2[5]
5321	3	2	5	5	4	4	3	3	
5323	1	4	1	4	2	5	2	2	
5326	4	7	2	1	1	3			3
5328	7	5	4	7	6	6	1	1	2
5377	6	6	3	6	3	1			
5260	5	3	6	3	5	2		8	1
5339	8	1	7	2	7	7			
Balsam	2	8	8	8	8	8	8		8

[1] Original data based on six traits.
[2] Transformed data based on six traits.
[3] Original data utilizing a canonical variable.
[4] Canonical variables associated with Photo/Clone interaction.
[5] Canonical variables associated with Temp/Clone interaction.

One critical assumption associated with this index states that index I_1 is effective as a discriminator only when the genotypic correlations between the traits included in the index are high. The following statistics were calculated from the relation:

$$r_g = \hat{\sigma} G_{ij} \quad \sqrt{\hat{\sigma}^2_{G_{ii}}} \cdot \hat{\sigma}^2_{G_{jj}}$$

$$i,j = 1, \ldots, 3 \text{ (Falconer 1960)}$$

for both the original and transformed data.

All the correlations between the three traits of interest in Trial I were high, with the exception of the genotypic correlation between LFWT and HT for both the original and transformed data. Correlations based on the transformed data were slightly higher than those based on the original data (table 17). Index I_1, therefore, is an effective discriminator for Trial I. In Trial II, however, there are low genotypic correlations between the traits DIA and HT, and LFWT and HT for both the original and transformed data (table 18). This may indicate that index I_1 is not an effective discriminator in Trial II, possibly because of the large number of traits being considered.

Weight-free index.—Before evaluating this index, the assumptions that the distributions of the traits are similar (at least unimodal) and that selection of individuals with large measurements on each trait is desired were verified.

For Trial I, the trait HT was found not to be as important as the traits LFWT and STMWT, thus HT was omitted. Lower bounds for the remaining two

Table 17.—*Genotypic correlations between three traits based on original transformed data (n = 300) for Trial I*

Trait	Trait		
	LFWT	STMWT	HT
LFWT	1.0000[1]	0.8490	0.5139
	1.0000	.8464	.5574
STMWT		1.0000	.7513
		1.0000	.7974
HT			1.0000
			1.0000

[1] Upper figure is based on original data and lower figure on transformed data.

traits were obtained for each environment and then ranks were assigned to the index values within each environment. The lower bounds for both traits increased from environment 1 to environment 3, indicating improved growing conditions from the growth chambers to the greenhouse environments (table 19).

Ranks associated with index I_2 showed marked variation from one environment to another. For example, clones 5260, 5326, 5258, 5266, and 5377 were selected in environment 1, while clones 5266, 4879, 5258, 5334, and 5265 and clones 5334, 5258, 5266, 5326, and 5377 were selected in environments 2 and 3, respectively. The only clones selected in all three environments were 5266 and 5258 (table 20). This index appeared to be less consistent than index I_1 from one environment to another.

Index values were also summed over environments for each clone and ranks were assigned. Clones 5334, 5266, 5258, 5326, and 4879 were chosen (table 15). For both index I_1 and I_2 only clones 5334 and 5266 were chosen by each index.

Table 18.—*Genotypic correlations (over all clones) for six traits based on the original and transformed data (n = 256) for Trial II*

Trait	Trait					
	DIA	HT	LFWT	STMWT	RTWT	LFAREA
DIA	1.0000[1]	0.3267	0.9256	0.7143	0.8512	0.9619
	1.0000	.2764	.9031	.6923	.7879	.9222
HT		1.0000	.4451	.8644	.6731	.6060
		1.0000	.4730	.8251	.6724	.6056
LFWT			1.0000	.7774	.9192	.9707
			1.0000	.8248	.8921	.9620
STMWT				1.0000	.8588	.8676
				1.0000	.9132	.9048
RTWT					1.0000	.9455
					1.0000	.9569
LFAREA						1.0000
						1.0000

[1] Upper figure based on original data and lower figure based on transformed data.

Table 19.—*Lower bounds for two traits LFWT and STMWT by environment*

Trait	Environment		
	1	2	3
LFWT	7.223	9.458	11.451
STMWT	2.580	5.987	7.379

For Trial II, index I_2 was not evaluated for each of the 16 environments. Based on the ranks associated with index I_2 values over all environments, clones 5323 and 5326 were selected (table 16). Only clone 5323 was chosen by both I_1 and I_2.

Adaptation index.—Regression analyses of the clone by environment means on the environment means (over all clones) were performed for each trait. Only the transformed data were used, since the logarithmic transformation helped to linearize the data as well as decrease the dependence between means and variances.

Table 20.—*Ranks associated with index I_2 values based on two traits by environment for Trial I*

Clone	Environment		
	1	2	3
4877	9	24	13
4878	21	22	16
4879	11	2	8
5258	3	3	2
5262	14	6	11
5263	8	20	15
5264	12	8	6
5265	13	5	7
5266	4	1	3
5267	23	23	23
5271	24	25	25
5272	19	13	17
5321	20	21	24
5322	25	16	14
5323	10	7	10
5324	17	11	19
5325	6	9	9
5326	2	10	4
5327	18	18	18
5328	22	14	12
5331	15	12	20
5332	16	15	21
5334	7	4	1
5260	1	19	22
5377	5	17	5

By definition, a clone is stable across all environments for a particular trait if the slope of the straight line fitted through the above-mentioned means is near 1.0 (Finlay and Wilkinson 1963). Via the method of simple least squares, these lines were fitted and regression coefficients were obtained. Considering Trial I and the trait LFWT, clones 5258, 5325, 5326, 5327, and 5377 are stable, while clones 5321, 5322, 5334, and 5260 are highly unstable. For the trait STMWT, clones 4878, 5324, 5325, 5326, 5327, and 5377 are stable, while clones 5271, 5322, 5334, and 5260 are unstable (table 21). For the trait HT, clones 5258, 5262, 5264, 5265, 5272, 5323, 5325, and 5377 are stable, while clones 5271, 5334, and 5260 are unstable. All three traits considered jointly revealed clones 5325 and 5377 as stable, and clones 5334 and 5260 as unstable.

To assist data interpretation, we made scatter diagrams by plotting clonal regression coefficients (slopes) against clone means (over all environments) for each of the three traits. Using figure 5, we determined the general significance of the location of the points on these scatter diagrams. For the trait LFWT, clones 5258(4), 5265(8), and 5266(9) appear well-adapted to all environments; for the trait STMWT, clones 4879(3), 5258(4), 5266(9), and 5326(18); and for the trait HT, clones 4879(3), 5262(5), 5263(6), and 5266(9) (figs. 6, 7, and 8).

Table 21.—*Estimated regression coefficients associated with the simple linear regression of clone by environment means on environment means for three traits, based on the transformed data*

	LFWT		STMWT		HT	
Clone	a[1]	b[2]	a	b	a	b
4877	0.044	0.915	0.128	0.798	0.471	0.769
4878	-.206	1.126	-.034	.989	.182	.920
4879	-.322	1.287	.029	1.108	-.073	1.063
5258	.166	.981	.096	1.083	-.018	1.019
5262	-.252	1.206	.000	1.088	.027	1.036
5263	.148	.862	.123	.907	.176	.942
5264	-.371	1.340	-.162	1.157	-.049	1.030
5265	-.106	1.190	-.092	1.127	-.066	1.035
5266	.063	1.099	.037	1.097	-.197	1.122
5267	.239	.675	-.207	.934	.056	.925
5271	.184	.583	.078	.598	.314	.794
5272	.077	.929	-.117	1.112	.002	1.016
5321	.797	.308	.163	.695	.246	.834
5322	-1.118	1.804	-.658	1.510	-.901	1.386
5323	-.172	1.189	-.023	1.089	.076	.973
5324	.187	.846	-.029	1.014	-.418	1.191
5325	.049	1.022	.062	1.018	-.002	1.012
5326	.091	.993	.202	.956	.160	.934
5327	-.049	1.009	-.007	.960	.234	.887
5328	-.304	1.258	-.365	1.261	-.546	1.206
5331	.349	.722	.163	.848	-.094	1.055
5332	.379	.649	.092	.905	-.067	1.054
5334	-.623	1.590	-.245	1.341	-.442	1.241
5260	.785	.363	.705	.353	.943	.540
5377	-.036	1.054	.060	1.051	-.012	1.015

[1] Intercept.

[2] Slope.

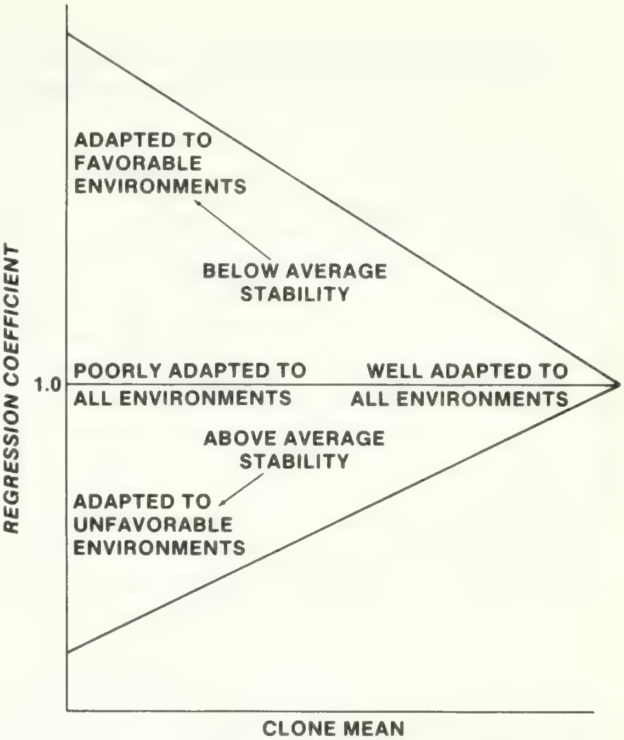
ADAPTED TO FAVORABLE ENVIRONMENTS
BELOW AVERAGE STABILITY
REGRESSION COEFFICIENT
1.0
POORLY ADAPTED TO ALL ENVIRONMENTS
WELL ADAPTED TO ALL ENVIRONMENTS
ABOVE AVERAGE STABILITY
ADAPTED TO UNFAVORABLE ENVIRONMENTS
CLONE MEAN

Figure 5.—*General interpretation of the scatter diagram when clonal regression coefficients are plotted against clone means.*

In Trial II the slopes of the fitted lines indicated that balsam poplar was unstable for all traits while clone 5326 was stable for all traits except DIA (table 22).

Index I_3 (adaptation index) has a form similar to index I_2 because individuals are selected on the basis of large values of clone means (over all environments). In addition, individuals are selected on the basis of small values of the squared deviations of the slope about the mean slope, 1.0 (i.e., min $(b_i - 1.0)^2$). These requirements led to the form of index I_3:

$$I_3 = (\hat{\mu}_{i.} - k_1)\{k_2 - (b_i - 1.0)^2\}$$

The lower bounds for the expressions μ_i and $(b_i - 1.0)^2$ were obtained for the traits used in Trials I and II (table 23), and index I_3 values and associated ranks were calculated. For Trial I, clones 5266, 5258, 5265, 5326, and 5325 were chosen for the trait LFWT; clones

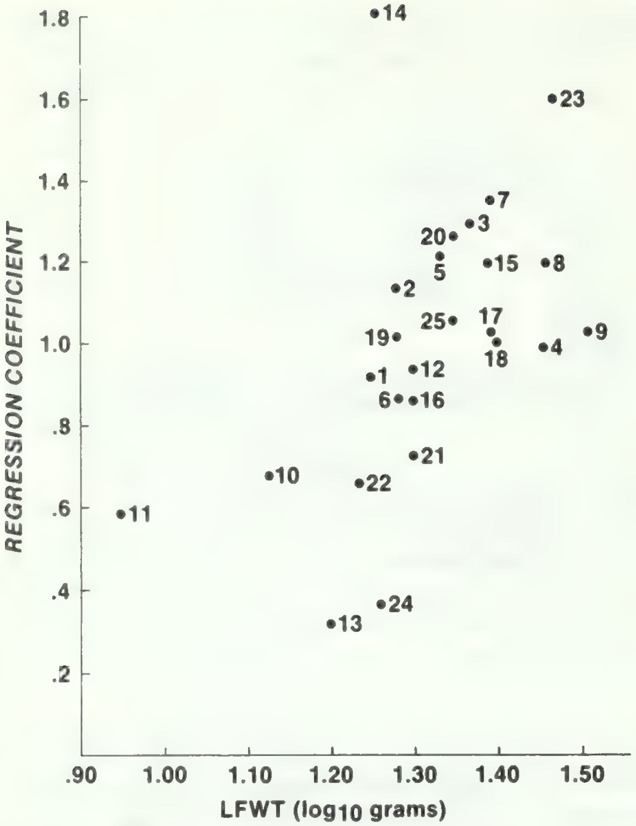

Figure 6.—*Clonal regression coefficients (slopes) plotted against clone means (over all environments) for the trait LFWT, based on the transformed data.*

5258, 5326, 5266, 4879, and 5377 for the trait STMWT; and clones 5262, 5263, 4879, 5266, and 5332 for the trait HT (table 15). When all three traits were considered jointly, only clone 5266 was selected. Due to the dependence between traits, the index values could not be summed over all traits for each clone.

In Trial II, clones 5323 and 5326 were chosen when each of the six traits were considered separately, even though clone 5326 ranked low with respect to the trait DIA. Balsam poplar ranked last for all six traits (table 24), which is understandable since this clone is a naturally occurring *Populus* species and not a purposely chosen hybrid like the other seven clones.

An alternative procedure was to construct index $I_3^{(0)}$ utilizing the th canonical variable associated with the clone source of variation in the MANOVA table (see Canonical index). The canonical variable:

$Y^{(2)} = 0.02016(\text{LFWT}) - 0.03383(\text{STMWT}) + 0.00455(\text{HT})$ was chosen for Trial I and the canonical variable

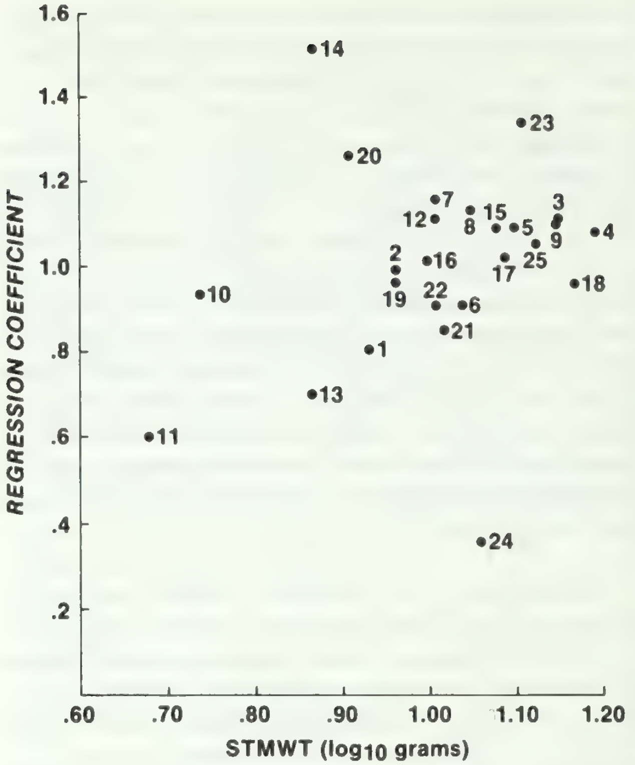

Figure 7.—*Clonal regression coefficients (slopes) plotted against clone means (over all environments) for the trait STMWT, based on the transformed data.*

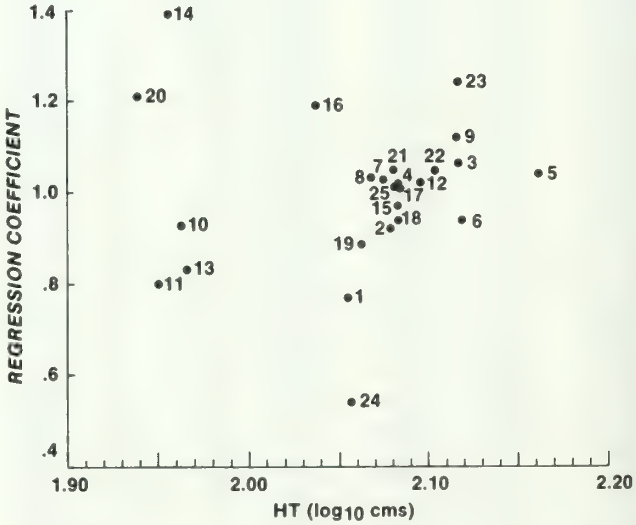

Figure 8.—*Clonal regression coefficients (slopes) plotted against clone means (over all environments) for the trait HT, based on the transformed data.*

Table 22.—*Estimated slopes of the straight lines fitted by regressing the clone by environment means on the environment means for six traits, based on transformed data (Trial II)*

Clone	Trait DIA	HT	LFWT	STMWT	RTWT	LFAREA
5321	0.942	0.926	0.881	0.942	1.019	0.872
5323	.927	1.008	1.111	1.093	1.132	1.034
5326	.490	.970	.992	.990	.983	1.020
5328	1.028	1.097	1.241	1.171	1.155	1.238
5377	1.243	1.087	1.243	1.159	1.164	1.142
5260	1.039	1.225	.959	1.016	.823	1.018
5339	1.189	.983	1.047	1.071	1.037	1.061
Balsam	.546	.703	.525	.556	.687	.614

$$Y^{(2)} = -0.03020(DIA) + 0.00437(HT) - 0.07773(LFWT) - 0.05162(STMWT) + 0.11780(RTWT) + 0.03984(LFAREA)$$

was chosen for Trial II.

Through this canonical variable, the clone, environment, and clone by environment means were transformed to produce new canonical means. Slopes were obtained by fitting lines through these new means—i.e., regressing the canonical clone by environment means on the canonical environment means.

Index $I_3^{(2)}$ was of the form

$${}_3^{(2)} = (\bar{Y}_i^{(2)} - 0.4258)\{0.8604 - (b_i^{(2)} - 1.0^2\}$$

or Trial I and

$${}_3^{(2)} = (\bar{Y}_i^{(2)} - 0.00272)\{0.4009 - (b_i^{(2)} - 1.0^2\}$$

or Trial II, where

$\bar{Y}_i^{(2)}$ = clone mean of canonical variable 2, and

${}_i^{(2)}$ = slope of line fitted through canonical variable 2 means.

Table 23.—*Lower bounds for two expressions which form index I_3 for the appropriate traits by trial, based on transformed data*

Trait	Trial I expression $\mu_{i.}$	 $(b_i-1.0)^2$	Trial II expression $\mu_{i.}$	 $(b_i-1.0)^2$
DIA	—	—	0.7623	0.2601
HT	1.9385	0.2116	1.5492	.0882
LFWT	.9522	.6464	.5170	.2256
STMWT	.6838	.4186	.1258	.1971
RTWT	—	—	-.0954	.0980
LFAREA	—	—	.7687	.1490

Table 24.—*Ranks associated with values of index I_3 for six traits, based on transformed data in Trial II*

Clone	Trait DIA	HT	LFWT	STMWT	RTWT	LFAREA
5321	4	5	4	5	2	4
5323	2	1	1	2	3	1
5326	7	2	2	1	1	2
5328	1	7	3	6	4	5
5377	3	3	5	4	7	3
5260	6	6	6	3	6	6
5339	5	4	7	7	5	7
Balsam	8	8	8	8	8	8

From the ranks associated with the values of index $I_3^{(2)}$, clones 5266, 5262, 5323, 5325, and 5264 were selected for Trial I and clones 5326 and 5339 for Trial II (tables 15 and 16).

For Trial I there seems to be no consistency between this index and the previous two indices. Perhaps another canonical variable should have been chosen, although the signs and magnitudes of the coefficients of $Y^{(2)}$ are acceptable from a selection viewpoint. In Trial II, the lack of consistency between the indices may be due to the large number of traits on which selection is based.

Curvature index.—Like the adaptation index, this index selects clones on the basis of one trait at a time over the range of some independent environmental measure. Because none of the clonal responses over environments in Trial I was quadratic, this index was not evaluated. In Trial II, this index was evaluated but an interpretation problem existed when the ranks associated with the index values for each of the six traits were considered simultaneously.

Consequently, the canonical variable 2 given in the previous subsection was used to obtain a linear combination of all six traits. For each clone the quadratic

$$Y_{ij}^{(2)} = a + bT_i + cT_i^2$$

where

T_1 = day temperature (17, 23, 29, 35°C) and
$i = 1, \ldots, 4; j = 1, \ldots, 8$

was fitted, as well as the quadratic over all clones. The curvature parameter, ρ, for each clone and over all clones was evaluated by setting $T = \bar{T} = 26$. Clones with curvatures near the average were considered stable and those with curvatures much above or below the average were considered to have below- and above-average stability, respectively. Clone 5326 exhibited average stability, while clone 5339 and balsam poplar showed below- and above-average stability, respectively (table 25).

Index I_4 was of the form

$$I_4 = (\bar{Y}_i^{(2)} - 0.00272)(0.00205 - [\rho_i - 0.00304])$$

where

$\bar{Y}_i^{(2)}$ has previously been defined,

ρ_i = i-th clonal curvature,

and the constant inside the absolute value signs is ρ.

From the ranks associated with the values of index I_4, clones 5326 and 5323 were selected (table 16). These results are consistent with those obtained via index I_2 and are inconsistent with the results obtained via indices I_1 and I_3.

Table 25.—*Regression coefficients for the model* $Y_{ij} = a + bT_i + cT^2_i$, *the parameters* ρ *and H for each clone, and the overall average*

Clone	Regression coefficients	ρ	H
5321	-1.26370 .10552 -.00170	0.00340	0.00127
5323	-1.26032 .10678 -.00173	.00346	.00134
5326	-1.04387 .09194 -.00147	.00294	.00115
5328	-1.57985 .12965 -.00217	.00434	.00154
5377	-1.08102 .08832 -.00132	.00264	.00104
5260	-.87136 .07313 -.00102	.00203	.00090
5339	-1.66792 .14504 -.00254	.00509	.00203
Balsam	-.29345 .01662 -.00019	.00038	.00003
Average	-1.13267 .09462 -.00152	.00304	.00104

Hamiltonian index.—Using only the data from Trial II and the estimated coefficients of the quadratic equations developed for the curvature index, the parameter H was calculated for each clone and over all clones. Clone 5377 exhibited average stability, while clone 5339 and balsam poplar showed below- and above-average stability, respectively (table 25). The interpretation of H is the same as that for parameter ρ.

From the ranks associated with the values of index I_5, which has the form $I_5 = (\bar{Y}_i^{(2)} - 0.00272)\{0.00101 - [H_i - 0.00104]\}$ with the constant inside the absolute value signs denoting H, clones 5377 and 5260 were selected (table 16). The results obtained from this index were completely different from those obtained from any of the other indices. Possibly the principle of conservation of energy does not hold and the function $H = f(g(x), h(x))$ is not constant for different values of x.

Distance index.—A discriminant analysis was performed on the original data and the generalized squared distance between each possible pair of clones was calculated considering the traits LFWT, STMWT, and HT. A pooled covariance matrix was used to ensure consistency with the standard analysis of variance assumption of equality of variance. Although a test for the equality of a group of variance-covariance matrices was made and resulted in the rejection of the null hypothesis H_o: $\Sigma_1 = \Sigma_2 = \ldots = \Sigma_p = \Sigma$ where p equals the number of clones, this test is not a good one. Even if one element of one of these matrices is different from the corresponding elements in the other matrices, H_o will be rejected.

A better plan is to look at the correlation matrices, one for each clone, and see if the signs and magnitudes of the coefficients are similar from one clone to the next. When this was done the correlation matrices were found to be quite similar.

Next a cluster analysis was performed on these clonal distances and a dendrograph was constructed to display the results. From this graph clones 5266, 5334, 5265, 5264, and 5326 were chosen for Trial I. In Trial II, clone 5328 and balsam poplar were selected (fig. 9). Recall that this technique, however, separates very poor clones also. Based on the clonal means over all environments for each of the six traits, balsam poplar was the poorest overall performer of the eight clones. Balsam poplar, therefore, was rejected and clone 5323 was selected instead (fig. 10). With the exception of index I_1 based on the original data, balsam poplar was ranked the lowest of all eight clones by all the other indices considered so

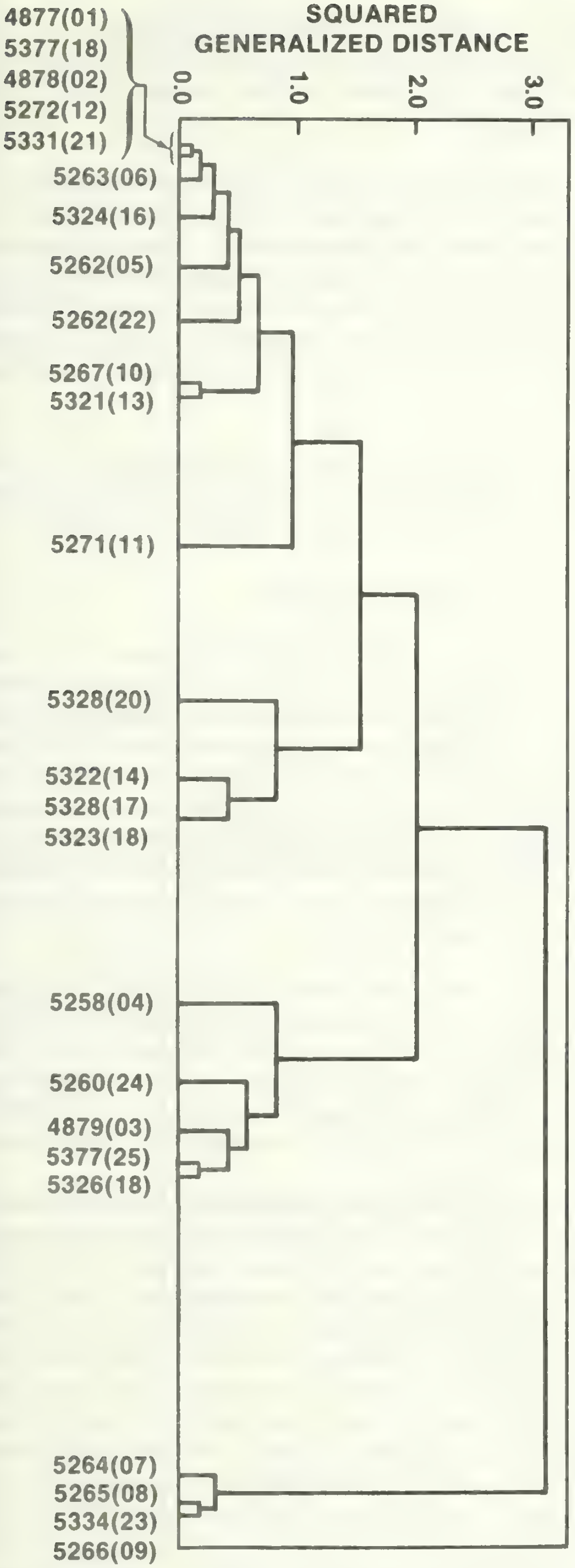

Figure 9.—*Dendrograph displaying the results of a cluster analysis performed on the generalized squared distances between 25 clones based on three traits in Trial I.*

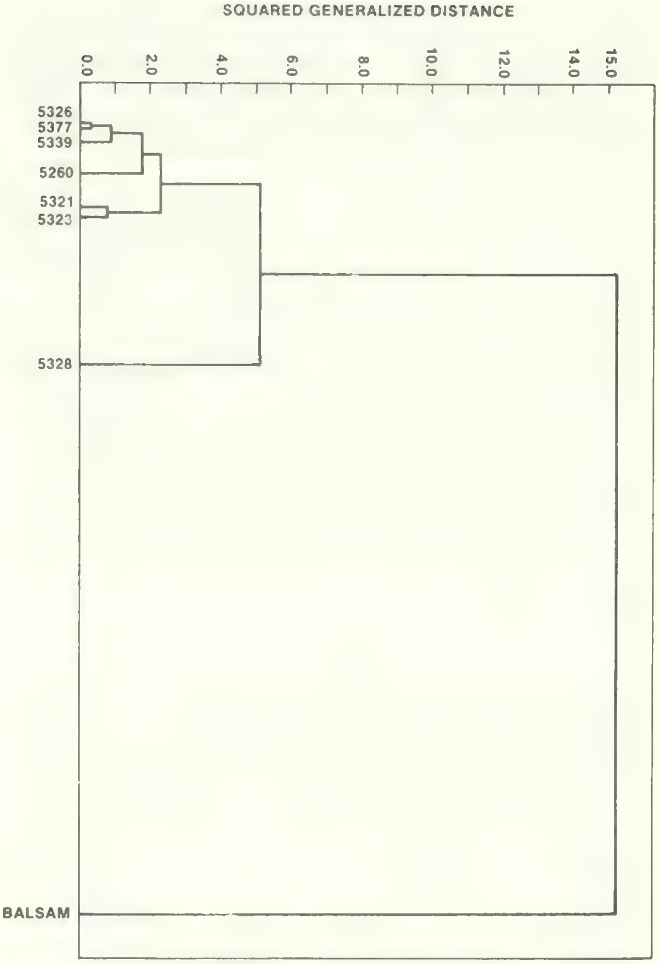

Figure 10.—*Dendrograph displaying the results of a cluster analysis performed on the generalized squared distances between eight clones based on six traits.*

far. To interpret the dendrograph correctly when widely different clones are present, the mean clonal response over all environments for the traits of interest must be considered.

The results obtained via index I_6 agree closely with those obtained by index I_1 for Trial I, but are inconsistent with all the other indices for Trial II.

Canonical index.—A multivariate analysis of variance was performed on the combined data over all environments with all traits considered jointly for both Trials I and II. The form of the univariate analysis of variance associated with each trait prior to the multivariate analysis was identical to that assumed for the H-S index in Trials I and II (table 11).

Canonical variables were derived from the partial sums of squares and cross-products matrix due to the clone by environment interaction for Trial I. For Trial II, canonical variables associated with both the partial sums of squares and cross-products matrices due to the photoperiod by clone and temperature by clone interactions, respectively, were calculated.

Generally the first two canonical variables account for 80 percent or more of the total variation in the data and thus are good for data condensation and description purposes (table 26). These first two canonical variables, however, are poor discriminators. The means of canonical variable 1 (one for each clone) within each environment tend to cluster around the overall mean. This is not true for the means of canonical variables 2 and 3. As a result, the plotting of canonical variable 1 means versus canonical variable 2 means yielded no good clonal separation, but the plotting of the means of canonical variables 2 against 3 did.

For trial I, three distinct clusters of points appeared, one for each environment, and the superior clones stood out clearly. Clones 5266(9), 5334(23), 5265(8), 5262(5), and 5263(6) were selected (fig. 11). The results of this index also compare favorably with those obtained by the H-S index, I_1, and the distance index, I_6.

For Trial II, four distinct groups of points were exhibited by both plots, one for each photoperiod or temperature level.

Considering the means of canonical variables 2 and 3 associated with the photoperiod x clone interaction, clones 5323(2) and 5328(4) were chosen (fig. 12). When the means of $Y^{(2)}$ and $Y^{(3)}$ associated with the temperature x clone interaction were considered, the selection of clones was not so obvious. Balsam poplar (8) was definitely the poorest performer, while clones 5260(6) and 5339(7) were "best" at two out of the four temperature levels (fig. 13). One reason for this dilemma might be the magnitude and signs associated with the coefficients of the canonical variables. For example, the signs of the coefficients for the traits LFWT and RTWT for the temperature x clone interaction are reversed as compared to coefficients for the same traits and corresponding canonical variable related to the photoperiod x clone interaction.

Table 26.—*Coefficients of each canonical variable (CANVAR) and the percentage of the total variation explained by each CANVAR for Trial I*

Canonical variable	Trait LFWT	STMWT	HT	Percentage
1	-0.01614	0.04589	-0.00257	59.12
2	.01842	-.02041	.00257	24.57
3	-.00804	-.00979	.00709	16.31

Another reason was that the elements of the partial sums of squares and cross-products matrix associated with the temperature x clone interaction were much larger than the elements of the corresponding matrix related to the photoperiod x clone interaction. Thus, the temperature x clone means were more variable than the photoperiod x clone means.

The results of I_7 based on the photoperiod x clone interaction agreed with those obtained from index I_6, but not with any of the other index results.

Appraisal of index reliability

Confidence intervals about the values of indices I_2 through I_5 were determined to appraise the reliability of the indices. However, due to the large variances and positive covariances between traits, the approximated variances associated with some index values were so large that confidence intervals were meaningless. A more useful approach was to apply an index with coefficients estimated from existing data to new data and vice versa. This was done for indices I_1 through I_3.

Index I_1 with coefficients derived from Trial I was applied to both the original and transformed data from Trial II, and ranks were assigned to the resulting index values. Clones 5323 and 5328 were chosen. These results agreed with those obtained by index I_6 and I_7 based on the data from Trial II only.

To apply index I_1 with coefficients, b, derived from Trial II to Trial I, the coefficients had to be recalculated because not all traits were present in both data sets. From the ranks associated with the values of this latter index, clones 5326, 5377, 5334, 5266, and 5325 were selected. With the original index I_1 clones 5334 and 5266 were chosen. Apparently the index derived from an experiment involving few environments and many clones gives more reliable results than one obtained from an experiment involving many environments and few clones.

Similarly, index I_2 with coefficients derived from Trial II was applied to Trial I, and clones 5334, 5266, 5258, 5326, and 4879 were chosen. These results compared favorably with those obtained by index I_2 when it was derived from and used in Trial I. When

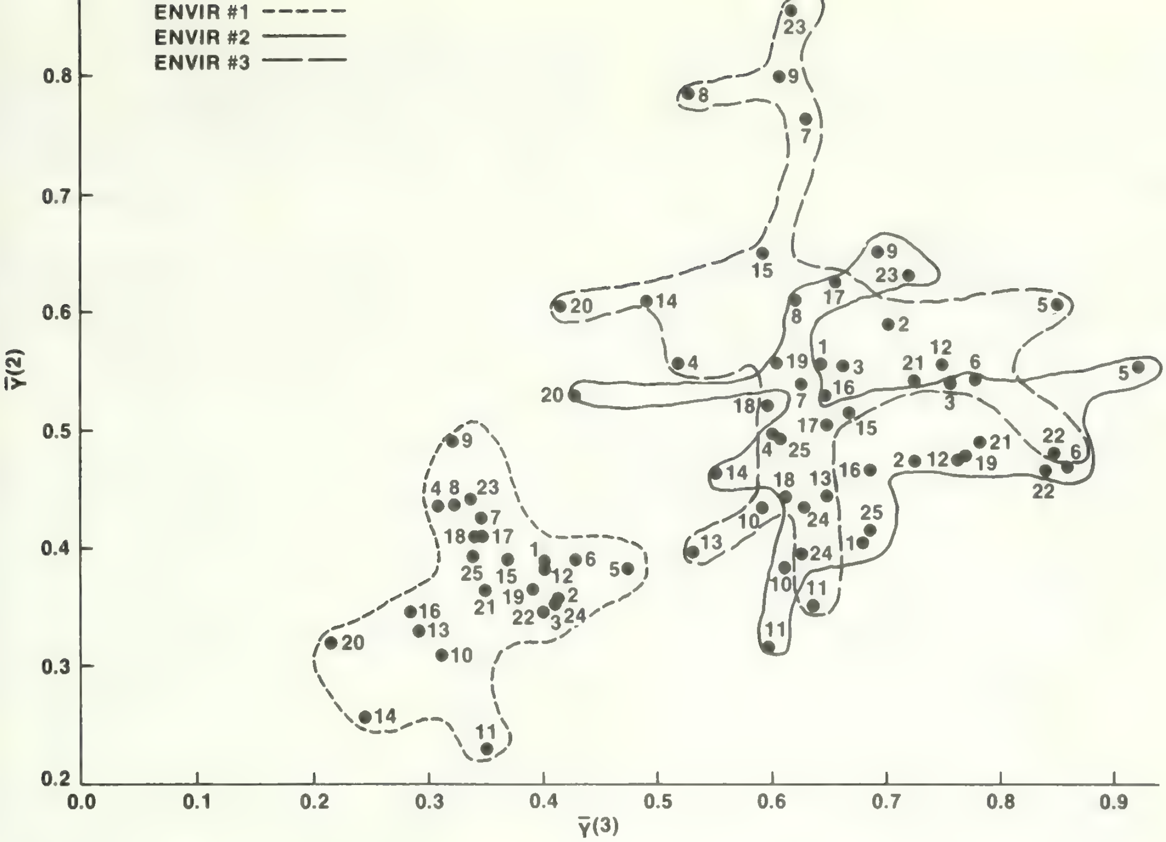

Figure 11.—*Plot of the means of canonical variable 2 versus the means of canonical variable 3 for each environment based on three traits for Trial I ($Y^{(2)}$ and $Y^{(3)}$ are associated with H_{CE}).*

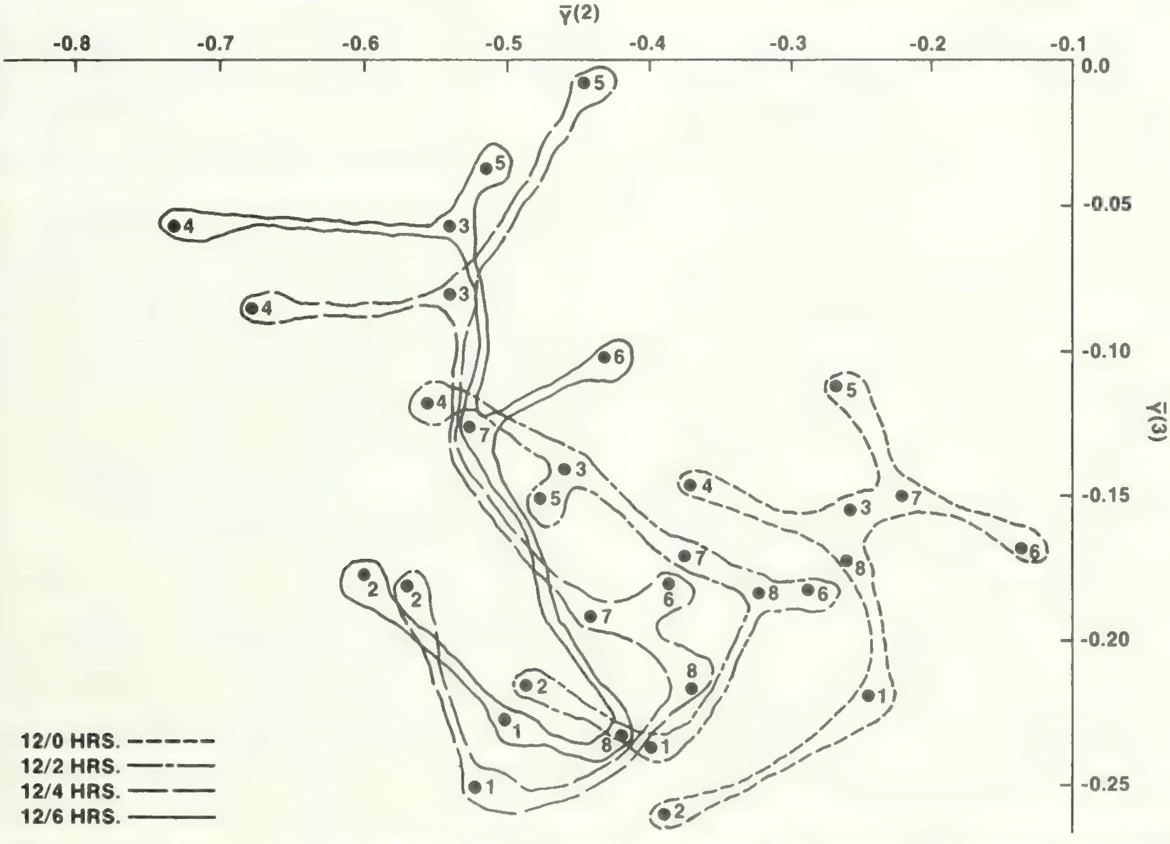

Figure 12.—*Plot of the means of canonical variable 2 versus the means of canonical variable 3 for each photoperiod level based on six traits in Trial II ($Y^{(2)}$ and $Y^{(3)}$ are associated with H_{PC}).*

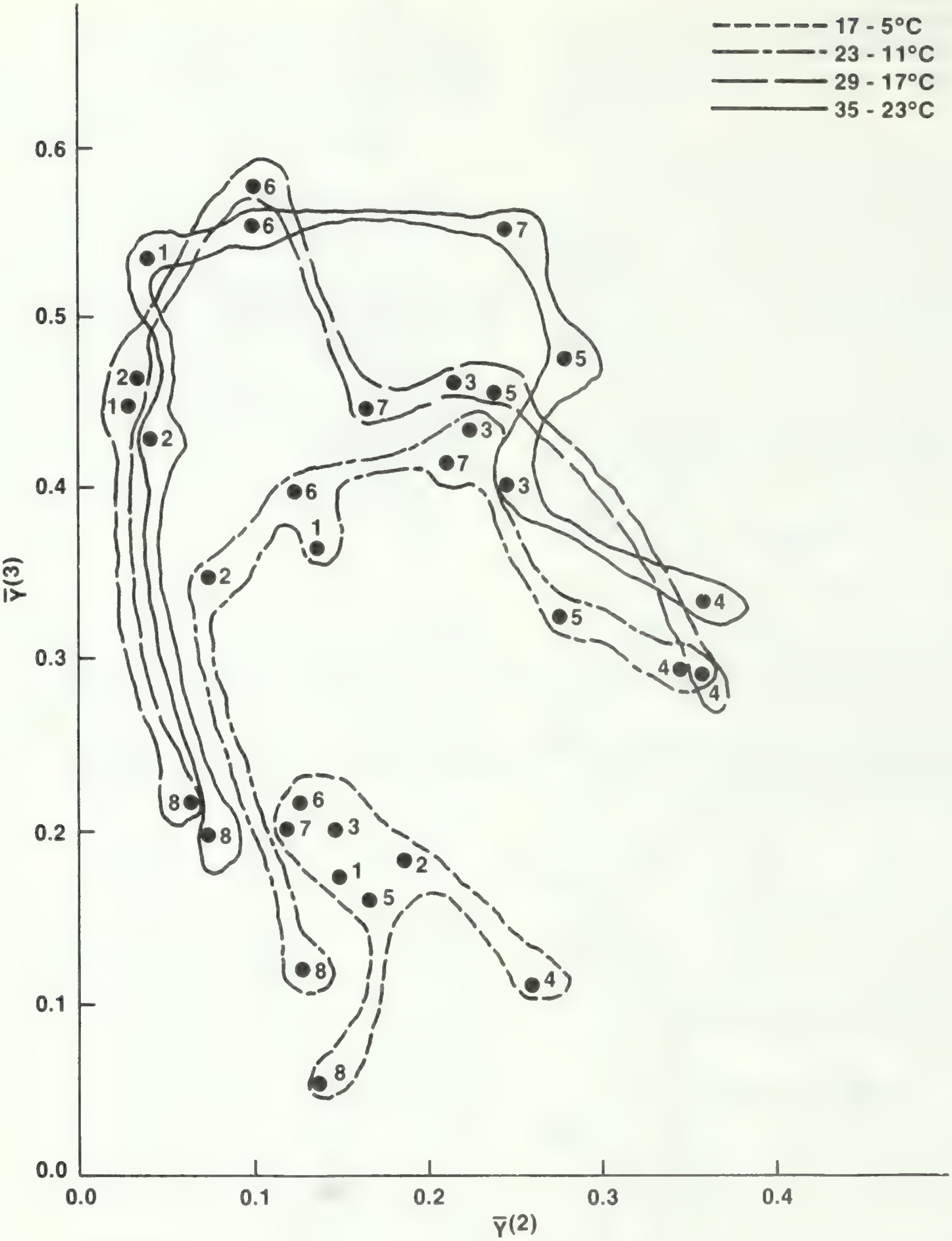

Figure 13.—*Plot of the means of canonical variable 2 versus the means of canonical variable 3 for each temperature level based on six traits in Trial II ($Y^{(2)}$ and $Y^{(3)}$ are associated with H_{TC}).*

index I^2 with coefficients derived from Trial I was applied to Trial II, clones 5323 and 5326 were selected. Lower bounds derived from Trial I, however, could not be used in Trial II since these bounds were too high. These bounds, therefore, were set equal to zero because two of the three environments in Trial I were greenhouse environments with means for all traits significantly higher than those for the growth chamber environments of Trial II. Consequently, no valid comparisons could be made for index I^2 other than those already mentioned.

Similar problems with lower bounds arose when index I_3, based on Trial I, was applied to Trial II. Also, index I_3, with coefficients derived from Trial II, could not be evaluated for all clones when applied in Trial I. Only clones common to both experiments could be evaluated.

These results demonstrate the data-dependence of all the proposed indices and their coefficients. In other words, two experiments could not be combined if the clones associated with Trial II were grown under conditions different from those of Trial I.

The number of traits on which selection is based appears to influence the reliability of an index. For example, when the number of traits associated with index I_2 in Trial II was reduced from six to two—STMWT and SLA—and individuals were selected on the basis of large values of STMWT and small values of SLA, clones 5323 and 5328 were selected. When all six original traits were considered, clones 5323 and 5326 were chosen.

As a further extension, index I_1 with coefficients derived from Trial I was applied to first-year field data composed of clones 5321, 5326, 5323, and 5377. Clone 5323 was chosen after assigning ranks to the index values. This compares favorably with results obtained by indices I_6 and I_7 applied to Trial II.

The computations associated with indices I_6 and I_7 must be executed again whenever a new group of clones is tested.

Indices and their reliability

Five of the seven proposed selection indices were evaluated using data obtained from Trial I. The curvature and Hamiltonian indices were not evaluated because none of the clonal responses over environments was quadratic and no independent environmental measure could be associated with each environment.

All seven selection indices were evaluated using data obtained from Trial II.

In Trial I, reasonable consistency was exhibited by indices I_1, I_2, I_6, and I_7, which selected clones 5265, 5266, and 5334 in the top group of five superior clones. These results compare favorably with those obtained by Wray (1974).

In Trial II, the indices produced less consistent results than they did in Trial I. For example, out of nine cases (seven indices of which indices I_1 and I_2 were based on both original and transformed data), clone 5323 was in the top 20 percent five times and clones 5326 and 5328 were each included three times. The reliability of an index apparently decreases as the number of traits on which selection is based increases.

In Trials I and II the coefficients of index I_1 were estimated from both original and transformed data. Since the variances associated with the traits of interest tended to increase with increasing mean, and since the coefficients of index I_1 were based on estimated phenotypic and genotypic variances, the transformed data were thought to improve the reliability of index I_1. A comparison of index I_1 in Trial I based on both the original and transformed data revealed identical results. In Trial II the results of index I_1 based on both types of data were dissimilar. The data transformation (logarithms to the base ten), therefore, did not improve the reliability of index I_1.

Unlike the other indices, index I_1 has the built-in facility of assigning weights, either economic or biological, to the traits on which selection is to be based. The sign and magnitude of these weights depend on the goals of clonal selection. In Trial I equal weights were assumed for lack of other information. As information about the relative importance of these traits becomes available it can be incorporated into the index and a new set of coefficients will be formed.

Kempthorne and Nordskog (1959) point out that index I_1 is reliable only when the genotypic correlations between the traits forming the index are high. These correlations were high for the traits in Trial I, and most, but not all, traits in Trial II.

Bridgwater (1972) used different weights and various combinations of six traits (height, diameter, total dry weight, specific gravity, volume, and number of limbs per foot) to construct many indices. The form of these indices was the same as index I_1 in our study. The expected gain (Falconer 1960) was employed as a means of deciding which index was best according to the selection goals. The expected gain was found to be high only when the traits height, diameter, and total dry weight were incorporated into the index. Bridgwater (1972) found that a reliable index was one containing traits with high genotypic correlations, such as the three listed above. Our results tend to support these findings.

Index I_1 with coefficients estimated from Trial I was applied to Trial II, and clones 5323 and 5328 were selected. This procedure produced good results compared with other indices. After some additional calculations, indices I_1 and I_2 based on data from Trial II were applied to Trial I, and clones 5334 and 5266 were among the top five superior clones. These results are acceptable when compared with the results of other indices.

Index I_1, when derived from an experiment involving few environments and many clones, gave more reliable results than when obtained from an experiment involving many environments and few clones.

Index I_2 is easy to calculate and, unlike index I_3, which bases selection on one trait at a time over several environments, index I_2 bases selection on several traits over one environment. The latter index is preferred because an average value over all environments can be calculated (environments are assumed independent). This cannot be done with index I_3 because the traits measured on the same plant are correlated with each other. Index I_3 must, therefore, be evaluated for each trait separately, which leads to interpretation problems if there are many traits. Even if a canonical variable is used to evaluate index I_3, its reliability is totally dependent on the canonical variable. A canonical variable which "explains" a large percentage of the total variation in the data—say 50 to 80 percent—is not desirable. Canonical variable 2 was usually a better discriminator, even though it "explained" only 10 to 30 percent of the total variation.

Wu (1973) originally proposed using the curvature of a quadratic equation that was a function of some independent environmental variable as a measure of adaptation, in contrast to the procedure outlined by Finlay and Wilkinson (1963). Wu (1973), however, stated that a variety is stable when its curvature approaches zero. We feel that a clone is stable across all temperatures if the curvature of a particular clonal response was near the overall average curvature. This idea was incorporated into index I_4.

Index I_5 was also evaluated based on data from Trial II, but did not perform as well as index I_4. Possibly no function, formed by the product of a growth and growth rate function, which remains constant over increasing temperature exists. Indices I_4 and I_5 were not evaluated in Trial I because some necessary information was absent. Index I_4 performed as well as index I_2 when both were based on data from Trial II. Clones 5323 and 5326 were selected in both cases.

Indices I_6 and I_7 are constructed by methods that involve complex computations, but existing computer programs partially solve this problem. Since final selection is a visual process, no mathematical functions are needed. Only the plotting of the computer results is required to produce a visual display.

The computations associated with index I_6 can easily be performed on any computer accepting FORTRAN. The computations associated with index I_7 are performed by an IBM-dependent package called SAS, which is not available for use on a non-IBM computer. A procedure called REGR, a subprogram of the SAS package, was used to perform MANOVAs and produce the canonical variables associated with various sources of variation of the assumed model. There is the limitation that the degrees of freedom associated with the source of variation due to regression must be 80 or less. Otherwise the procedure REGR breaks down and the plot of canonical means cannot be constructed.

In summary, an index based on existing data can be used reliably to select clones from a new data set or a combined data set of new and previously tested clones—provided the new clones are grown under environmental conditions similar to those under which the previously tested clones were grown. Given similar environments, all indices present useful information in condensed form. Because indices I_4 and I_5 can be computed only when some independent measured environmental factor produces a quadratic growth response, the other indices should be considered more general. Index I_2 should be chosen if computational base is important. However, index I_1 is best if selection is to be based on unequally weighted traits. Indices I_6 and I_7 are most useful if a graphical display is desirable.

PREDICTION OF FIELD GROWTH POTENTIAL

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How well do controlled-environment measurenents predict growth in the field? We present here uidelines for conducting field trials, methods for elating controlled-environment to field results, and ctual results of controlled-environment field-corelation studies.

Guidelines for Field Trials

The most important consideration is to conduct eplicated field trials under the environmental and ultural conditions that will prevail in actual pracice. Weed control, planting density, water managenent, and location should all be similar to intended ractice. Plots should be large enough to exclude dge effects, and genotypic composition should be vhat might be used in practice if specific clones were ccepted. In short, proven field procedures with proper tatistical design should be used.

For example, a study could run from 1 year to 3 ears, or to rotation age. Sixteen clones could be rown at four locations in a two-replicate, randomzed-block layout. The experimental plots would each ontain four clones spaced 6 feet apart. To eliminate order effects, each block would be bordered by two ows of whatever clone the experimenter desires. Basal iameter, total height, and top dry weight should be he variables on which selection is based. Root varables would be of interest to many silviculturists; ampling methods for poplar are available. Plot avrages would be analyzed so that the analysis would e balanced even if mortality occurred in some of he plots.

The ANOVA table analyses could be carried out or each year separately, then combined for all years.

Source	**d.f.**
Blocks/Locations	4
Locations (L)	3
Clones (C)	15
L x C	45
Error	60
Total	127

Several authors have examined the analysis of repeated-measurements experiments. Generally, analyses are kept simple if equal subclass numbers can be maintained. By utilizing plot averages, the experimenter has greater assurance of a balanced experiment.

The problem of plot size has also been investigated. They state that if most of the total cost is assignable on a per-plot basis, a small number of trees should be assigned to each plot. However, if the plot is too small, the problem of missing plots arises. Finally, the authors suggest that the biological adequacy of data collected from small plots depends on the magnitude of the correlation between the performance of varieties grown in mixture and that of the same varieties grown in pure stands. Four clones per experimental plot, therefore, appear minimally adequate for a field study.

Field study

In this study, three *Populus* clones, adapted to southern Canada (5260), southern Wisconsin (5377), and central Iowa (5339) were used. Tip cuttings taken from stock plants growing in the greenhouse were individually planted in commercial Jiffy-7 pellets, then placed under an alternating mist system on greenhouse benches. When the roots emerged from the pellets, 45 of the plants were planted in five Latin square designs at each of two locations—the State Nursery in Ames, Iowa (latitude 42°N) and the Hugo Sauer Nursery in Rhinelander, Wisconsin (latitude 45°N). Three degrees difference in latitude was enough to give markedly different environments, and hence different growth patterns were expected. High levels of nutrients and moisture were maintained in both locations. Stem height and number of leaves were recorded every 2 weeks. In addition, at approximately 30-day intervals (July, August, and September), a destructive harvest was made of one Latin square (three plants per clone, three clones), and stem height, stem diameter, stem dry weight, leaf number, leaf area, leaf dry weight, and total top dry weight were measured. This procedure was repeated in 1971, 1972, and 1973 at both locations.

Growth room

The three *Populus* clones were placed in Latin square designs in Percival growth chambers (three plants per clone, three clones, three photoperiods) to examine the productivity of individuals as affected by genotype and photoperiod. Cuttings were taken from stock plants and rooted under mist, then transferred into photoperiods of 13, 14, and 15 hours, with day temperature of 25°C and night temperature of 15°C. High nutrient and moisture levels were maintained throughout the experiment. Stem height and number of leaves were recorded approximately every 4 days until the end of the experiment, when all plants were harvested and measured as in the field study. This portion of the study was replicated four times, with the total growing period being either 6 weeks (one time) or 7½ weeks (three times). Results were analyzed with correlation analysis as well as simple ranking according to size.

Field, first-year growth

Clones were ranked first, second, or third on the basis of their size at the end of each growing period for all 3 years. This was done for all seven variables measured at both locations.

Wisconsin #5 (W-5) ranked first or tied for first with Crandon (Cr) for all variables measured for all three growing seasons at both locations. In Ames, the ranking was W-5, Cr, Tristis #1 (Tr) for each variable measured for both 1971 and 1973; for 1972, the ranking was always W-5, Tr, Cr. Similarly, in Rhinelander, W-5 ranked first or tied for first with Crandon for all variables measured for years 1971 and 1973; for 1972, the ranking was always W-5, Tr, Cr. In general, growth trends were the same at both locations for the years 1971 and 1973; 1972 growth differed from those 2 years, but differed in the same way at both locations.

To supplement the harvest data, the seasonal growth patterns of the clones were examined. Tr consistently set bud by mid-July in Ames, whereas in Rhinelander it grew longer but more slowly than during the first half of the growing season. In Ames, Tr showed approximately the same growth trends for all 3 years. At Rhinelander, however, Tr grew differently in different years. At the end of the 1972 growing season, for example, the total top dry weight of Tr in Rhinelander was almost twice that in Ames, although in 1973 the total top dry weights were almost identical.

Cr grew throughout the growing season at both locations for all 3 years, although it did not grow well at either location in 1972. In 1972, Cr grew best in Ames with respect to stem height, stem diameter, and leaf number, while in Rhinelander it grew best with respect to leaf weight, total top dry weight, and leaf area; stem weights were nearly identical. In 1973, Cr grew much better in Rhinelander with respect to stem height, stem diameter, and leaf area; other variables were similar in both locations, with the exception of stem weight and total top weight, which were slightly larger in Ames.

By the end of each of the three growing seasons in Ames, W-5 far surpassed Cr and Tr for all variables measured. In Rhinelander, W-5 usually ranked ahead of the other two clones. The difference between the first- and second-ranking clones, however, was not as consistently large as in Ames. In 1972, W-5 grew better with respect to six variables at the Rhinelander site, with only tree diameter being slightly larger at Ames. In 1973, W-5 grew better with respect to six variables at the Ames site, with only leaf area being slightly larger at Rhinelander.

Field, 2- and 3-year growth

Trees that were not harvested by the end of the 1971 and 1972 growing seasons were left to grow until the end of the 1973 season. Rankings for 2-year-old material in Ames were W-5, Cr, Tr for the variables stem height and stem diameter, and W-5, Tr, Cr for stem weight. Rankings for 2-year-old material left at Rhinelander were W-5, Tr, Cr for all variables measured. All three clones, however, were larger in Rhinelander than in Ames after 2 years. For example, Tristis stem weight at Rhinelander was approximately six times that in Ames, and W-5 stem weight was approximately twice that in Ames. This is most probably a result of more frequent irrigation d fertilization in Rhinelander. Rankings for ma- rial left 3 years (planted spring 1971, harvested ll 1973) at the Ames location were Cr, W-5, Tr for l variables measured. At Rhinelander, the rank- gs were W-5, Cr, Tr for all variables measured.

In general, after 3 years' growth, Cr grew much etter at Ames, W-5 grew somewhat better at hinelander, and Tr grew only slightly better at Ames.

rowth chamber

Clones were ranked first, second, or third for each ariable at the end of the growing period. The one rowth period of 6 weeks was combined with the ree growth periods of 7½ weeks, and the pooled eans were used as a basis of comparison. Thus, each ean value represented 12 trees (three trees per one, four replications).

In the 13-hour photoperiod the ranking was W-5, r, Tr for the variables stem height, stem diameter, af weight, number of leaves, and total top weight; r the variable leaf area, ranking was Cr, W-5, Tr. the 14-hour photoperiod the ranking was again -5, Cr, Tr for the variables number of leaves, leaf eight, leaf area, stem weight, and total top weight; ut the stem diameter ranking was W-5, Tr, Cr. Stem eight exhibited a third order: Cr, W-5, Tr. In the 5-hour photoperiod treatment, the ranking was W- Cr, Tr for leaf weight, number of leaves, and leaf rea. Ranking for stem height, stem weight, and em diameter was W-5, Tr, Cr. Thus, W-5 ranked rst in all variables except 13-hour leaf area and 14- our stem height. Tr ranked last in 16 of the 21 easurements. Differences among clones were least the 13-hour photoperiod, greater in the 14-hour hotoperiod, and usually greatest in the 15-hour hotoperiod.

To quantify the relations for the measured variables between growth room and field growth, correlation matrices were calculated for three combinations of variables: (1) all variables in one location with all variables in the same location; (2) each variable in one photoperiod with each variable in the same photoperiod; and (3) each variable in each location with each variable in the different photoperiods. Thus, it was possible to get "r" values, for example, between stem height in Ames and stem height in a certain photoperiod (table 27).

Discussion

By examining the values in table 27, it can be seen that the 13-hour photoperiod yielded the poorest growth-chamber and field correlations. This would indicate there is less discrimination in ranking of clones in this photoperiodic treatment than in the longer photoperiods. The results, indeed, showed that the magnitude of the difference in performance between the three clones was least under the 13-hour treatment. Higher "r" values were obtained between field and 14-hour growth-chamber performance, with the highest values being obtained between field growth and 15-hour growth. Greatest differences in performance between clones were observed in the growth room at the longer photoperiods.

An average correlation value was calculated for each location and photoperiod; this value increased progressively by photoperiod for both locations. Thus, ranking of clones between the growth room and the field appears consistent for each variable measured, and variability in the field when averaged over several trials is evidently not large enough to disrupt this ranking.

able 27.—*Correlation coefficients ("r") between growth chamber and field growth, by growth chamber photoperiod and field location, with clones and years pooled*

Field location	Growth chamber photoperiod	SH	SD	LW	TTW	LA	LN	SW	XR
mes	13HR	0.82	0.44	0.44	0.57	0.31	0.60	0.90	0.58
	14HR	.33	.91	.79	.83	.79	.81	.82	.75
	15HR	.80	.85	.86	.88	.78	.89	.90	.85
hinelander	13HR	.65	.34	.26	.34	.32	.47	.65	.43
	14HR	.30	.65	.70	.59	.69	.66	.53	.59
	15HR	.61	.61	.56	.59	.68	.73	.65	.63

Values for the correlations between Ames and the three photoperiods are larger than those between Rhinelander and the three photoperiods. This may be because there was less difference between the first- and second-ranked clones at Rhinelander for many variables.

Ranking was consistent in the field at both locations for 1971 and 1973. Although W-5 did rank first in 1972 also, the fact that the rankings were inconsistent with the other 2 years with respect to Tristis and Crandon was due to the poor growth of Crandon in 1972. It is possible that differences in climate caused this difference in growth pattern. First, the monthly averages in temperature for June, July, August, and September were all below the 10-year average at the Ames location (National Oceanic and Atmospheric Administration 1972). Second, the monthly solar radiation totals for June, July, and August were lower in 1972 than in 1971 at Ames. Third, the percentage of possible sunshine days (100 percent = full sun) was significantly below average for July, August, and September in 1972, and below average for July and August in 1971 and 1973 (Waite and Shaw 1961). Temperature readings also were below normal for June, July, August, and September at the Rhinelander location in 1972.

By the end of the third year at Ames, Crandon was firmly in first place. Tristis continued to set bud early in the season at Ames, resulting in its being considerably behind the other two clones after 3 years.

This study showed that there was consistency in ranking of clones between the growth chamber and the field for many variables for 1- and 2-year growth. Although growth differences did occur between years, the variability, when averaged over several years, was not enough to disrupt these rankings.

Therefore, it seems that it may be possible to estimate initial field growth potential of clonal material by means of a preliminary analysis of selected variables when the material is grown in controlled environments.

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Methods of rapid, early selection of poplar clones for maximum yield potential: a manual of procedures. Gen. Tech. Rep. NC-81. St. Paul, MN: U.S. Department of Agriculture Forest Service, North Central Forest Experiment Station; 1982. 49 p.

Instructions, illustrated with examples and experimental results, are given for the controlled-environment propagation and selection of poplar clones. Greenhouse and growth-room culture of poplar stock plants and scions are described, and statistical techniques for discriminating among clones on the basis of growth variables are emphasized.

KEY WORDS: Controlled-environment, *Populus,* growth, selection indices, hybrids.

United States Department of Agriculture

Forest Service

North Central Forest Experiment Station

General Technical Report **NC-82**

Estimating Economic Impacts of Timber-Based Industry Expansion in Northeastern Minnesota

Daniel L. Erkkila, Dietmar W. Rose, and Allen L. Lundgren

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ESTIMATING ECONOMIC IMPACTS OF TIMBER-BASED INDUSTRY EXPANSION IN NORTHEASTERN MINNESOTA[1]

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Minnesota has found itself, not unlike other Lake States, in a situation where softwood supplies are decreasing. Pure softwood stands that are easily accessible and economically feasible to harvest are no longer readily available. Recent legislation closing the Boundary Waters Canoe Area to logging removed a substantial area of such stands. Much of the remaining softwood supply is not in pure stands but in mixed stands characteristically containing low-grade hardwoods such as aspen, birch, and balsam poplar. The softwood volume in many of these stands has been too small to harvest separately, but a large area of this mixed-species resource exists.

Fortunately, recent developments in the timber industry have introduced a technology to utilize this extensive resource. Waferboard, which can be made from a variety of hardwood species, promises to revitalize the Minnesota forest products industry in the 1980's. Consequently, what were once considered "low-value" hardwoods have suddenly become an important resource, in addition to providing an economically feasible means of getting at the scattered oftwood supply.

Serious questions arise, however, with the advent f such a shift in the forest products industry. Unbalanced age class distributions as well as less than optimal distribution of species and cover types present two major problems forest managers must face in the near future. In addition, in the absence of proper silvicultural treatments, forest stands have become less productive and more susceptible to insect and disease attack.

Industry expansion must be paced to match the availability of necessary species and the means of sustaining their harvest over time. Regional labor supplies and the necessary capital for investment could both become limiting factors with too high a level of development. On the other hand, the potential for increased socioeconomic benefits should be evaluated. New jobs, increased industrial growth, and a revitalization of the wood industry can contribute to increased regional economic stability. Forest managers and other decisionmakers need information about the timber resource, potentials for industrial development, and the socioeconomic impacts of potential developments in order to make plans for the future.

A recently completed forest inventory of Minnesota's forests (Spencer and Ostrom 1979) provides detailed information about the forest resource. Also, a newly developed Forest Resources Evaluation Program (FREP) tree growth projection system (USDA Forest Service 1979) provides detailed inventory projections, with and without timber harvesting, to aid in examining the impact of harvest options on the resource. The FREP system mimics the biological function of tree growth over time, allowing growth simulations of timber stands and projections of timber volumes standing (and perhaps removed) at some point in time.

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[1] *This work was carried out under a cooperative greement between the USDA Forest Service—North Central Forest Experiment Station, and the Univer ity of Minnesota.*

Any increase in forest activity, such as increasing the allowable cut, will also have regional socioeconomic impacts. These impacts are not always easy to identify at first glance, but they can be evaluated using a submodule of the Minnesota Regional Economic Impact Forecasting and Simulation (REIFS) model (Maki *et al.* 1979). Developed by personnel in the Department of Agricultural and Applied Economics, University of Minnesota, the model forecasts changes in the economy over time, either with or without major changes by man. That is to say, either the status quo is maintained over time with some assumed level of annual increase (e.g., a 4-percent increase in GNP/year), or substantial changes are made over time, perhaps to simulate the advent of new technology or markets.

The question arises, then, as to how one might link these two models in order to investigate various alternative timber management opportunities. Each alternative may or may not be associated with substantial regional economic impacts. Will new jobs be created? What will be the effect over time on the service industries by expansion in one sector? How will changes in the timber industry influence regional demographics in 20 years? The answer to the linkage question lies in the development of scenarios based on the output of the timber resource evaluation system (fig. 1).

This paper reports the results of a joint study by the University of Minnesota College of Forestry and the North Central Forest Experiment Station (USDA Forest Service) designed to:

(1) Develop methods of linking the FREP Lake States Tree Growth Projection System to the Minnesota Regional Economic Impact Forecasting and Simulation model for regional economic analysis, and

(2) Test these methods in northeastern Minnesota for a selected forest type by identifying a potential forest management strategy and evaluating its regional economic impact.

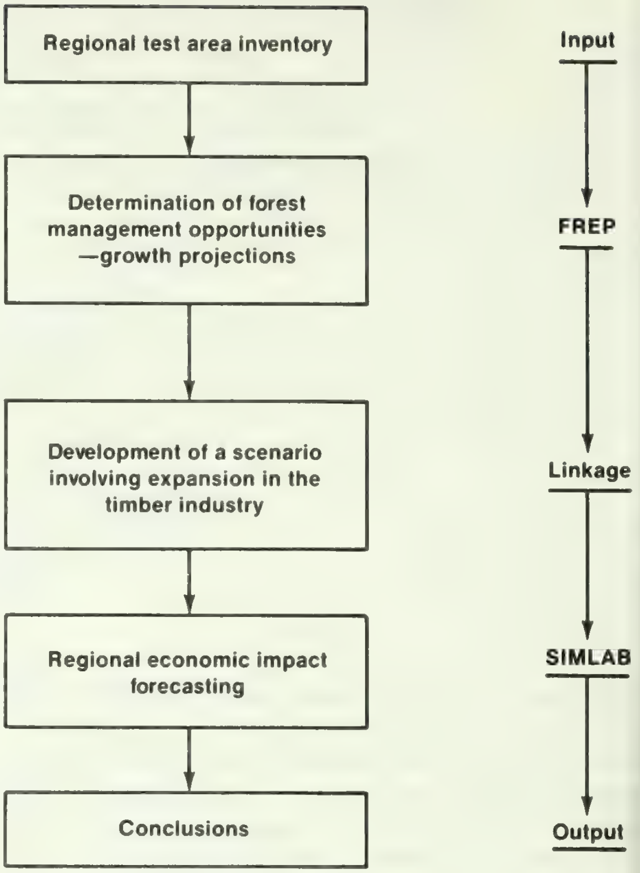
Regional test area inventory
Determination of forest management opportunities —growth projections
Development of a scenario involving expansion in the timber industry
Regional economic impact forecasting
Conclusions
Input
FREP
Linkage
SIMLAB
Output

Figure 1.—*Overview of study.*

MODEL DESCRIPTIONS

The FREP Tree Growth Projection System

One does not need to argue at great length about the advantages of growth projection models. At a time when the forest resource land base is dwindling, the ability to utilize models in which the timber resource can be manipulated via simulation is extremely useful. With a resource that is far too valuable to experiment with through trial and error, such simulation models aid researchers and forest decisionmakers by giving them the ability to, in effect, see into the future and realize the consequences of decisions made today (Shannon 1975).

The main element of the FREP tree growth projection system is its growth processor. Because the data base being worked with is a collection of forest inventory plots, the ability to predict growth on these plots is essential. The system developed by the North

Central Forest Experiment Station is an individual tree growth model. Such models have been widely used and discussed in the literature (for example, Arney 1974, Daniels and Burkhart 1975, Ek and Monserud 1974, Heggi 1974, Mitchell 1975). The FREP system is able to handle such forest management options as precommercial thinnings, partial cuttings, etc., as well as a stand's response to these activities (for a detailed description, see USDA Forest Service 1979).

The Minnesota Regional Economic Impact Forecasting and Simulation (REIFS) Model

The study of regional economics has been greatly enhanced by the use of the input-output model approach. The input-output table, representing an industry's role as a purchaser of goods in order to sell goods, is the heart of the model. The investigator constructing the table must become familiar with the regional economy (i.e., inter-industry transactions), if the model is to be of any value. If the table mirrors the region accurately, the analyst can experiment with hypothetical or expected changes in economic activity and examine the implications for industry outputs. Such changes may be linked to alternative government policies and programs or to different projections of investment behavior (Isard 1969). Further discussion of input-output model theory can be found in texts by Miernyk (1965), Leontief (1966), and Richardson (1972).

Applications to the forestry community are widespread (for example, Flick 1974, 1976; Hughes 1970, Kaiser 1969). The advantages of being able to predict direct and often more importantly indirect impacts resulting from industrial change can be numerous. With large industrial expansion (i.e., new forest products facilities), regional development may be significant.

The Minnesota Regional Development Simulation Laboratory, or SIMLAB, is the computer-based simulation module of REIFS consisting of the core regional input-output model. REIFS includes, in addition to the production module (i.e., input-output), the demand forecasting modules, auxiliary modules, operational control modules, and SIMLAB II, the interactive module. The demand forecasting modules include the export market, regional investment, and regional demand. Value added, employment, labor force, population, and households are all contained as auxiliary modules. For further description of REIFS, the SIMLAB User's Reference Manual is helpful (Maki *et al.* 1979).

NORTHEASTERN MINNESOTA TEST PROJECTION

The first phase of the study was to pick an area of Minnesota where forest management opportunities exist. USDA Forest Service Survey Unit 1, the Aspen-Birch Unit, was selected because the most up-to-date and complete data base for the regional economic impact model was available for this area (fig. 2). Table 1 shows the total land area by county along with the associated percentages of forest and commercial forest land (Arrowhead Regional Development Commission 1978).

In making a projection of this nature, one must identify what it is that may be of interest. In this instance, two observations were selected: (1) a comparison between two growth projections, one assuming timber harvest when silviculturally desirable, the other assuming no management activity at all, and (2) an indication of the harvest potential beyond the current level of cut.

As a start it was decided the projection would be made using the 1977 Minnesota inventory data. The two runs, with and without management, would project only plots of the aspen cover type in State ownership for one 10-year period. In both cases the plots would be brought up to 1980 as a starting point. Stand volumes by age and site were recorded, and the 10-year projection begun. When year 1990 was reached for both runs, the stand volumes were recorded, although in the management projection the appropriate silvicultural treatment, as built into the model, was carried out prior to the final stand tally. Consequently, the management run not only reflects the stand volumes in 1990 after harvest but also the removal volumes (table 2a). The acreage represented by each site index and age class combination is shown in table 2b.

Projection Observations

As noted, two management options were investigated in this test case.

In the no-harvest projection, the imbalances between age classes that existed in 1980 are continued. Additionally, not only is there an even larger standing volume of aspen type in the 45-65 year age class, but the 75 years and older age class also continues

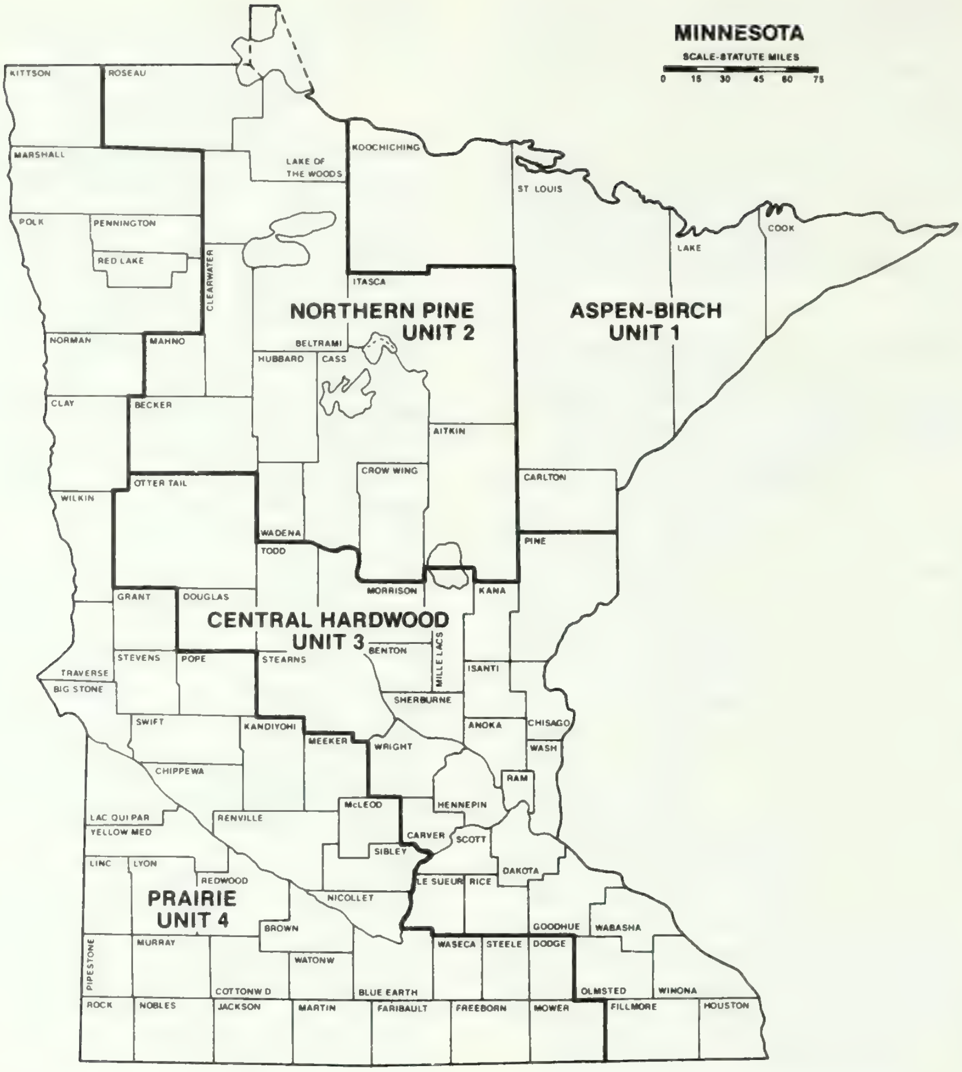

Figure 2.—*Boundaries of USDA Forest Service Survey Units 1-4.*

Table 1.—*Total land area, forested land, and commercial forest land, Region 1*

County	Land area	Forested	Commercial forest land
	Acres	*Percent*	
Carlton	551,800	61	57
Cook	861,400	99	74
Koochiching	2,001,300	89	63
Lake	1,319,800	96	73
St. Louis	3,899,100	83	68
Total	8,633,400	72	68

growth. This allows for overmature stands to become ready targets for insect and disease infestation, even beyond the maximum suggested rotation age of 70 years if sawtimber or veneer products are the desired ends (Perala 1977).

The managed run shows the removals for timbe especially in the oldest age grouping, in addition t a substantial reduction of volume in the middle-ag category, across all site indexes. This balancing ou reflects the need to manage according to site an geographical limitations with respect to rotation age This is, in effect, cashing in on the resource instea of losing it to deterioration by natural causes. It shoul be pointed out that the decrease in volume in the 3 years and below age group (for both the no-management and management runs) is caused by mortalit in the former and also thinning in the latter. Hence natural removals equal management removals o those sites where stands are overstocked.

Simulated removals on state-owned aspen land from 1980-1990 total 2,286,500 cords, an average o

Table 2a.—*Ten-year FREP growth projections for state-owned stands in Minnesota's aspen type, with and without management*

(In thousand cords)

Site index		Age class (years)			
		35 and below	45–65	75 and above	Total
Less than 40	1980	7.3	0	10.2	17.4
	1990 no management	11.6	0	11.6	23.2
	1990 managed	11.6	0	0	11.6
	Removals	0	0	10.2	10.2
40 to 59	1980	102.2	293.6	51.1	446.8
	1990 no management	117.8	335.5	126.5	579.8
	1990 managed	117.8	137.5	57.3	312.6
	Removals	0	180.8	51.1	231.9
60 or Greater	1980	813.8	1,730.6	281.7	2,826.2
	1990 no management	613.9	2,237.6	736.8	3,588.3
	1990 managed	613.9	643.2	71.9	1,329.0
	Removals	322.4	1,440.3	281.7	2,044.5
Total	1980	923.3	2,024.2	343.0	3,290.4
	1990 no management	743.3	2,573.1	874.9	4,191.3
	1990 managed	743.3	780.7	129.2	1,653.2
	Removals	322.4	1,621.1	343.0	2,286.5

Table 2b.—*Acreage represented by each site index and age class combination for 10-year FREP growth projections*

Site index	Age class			
	35 and below	45–65	75 and above	Total
Less than 40	1,451	0	1,451	2,902
40 to 59	18,404	28,454	9,831	56,689
60 or greater	49,167	94,299	27,705	171,171
Total	69,022	122,753	38,987	230,762

229,000 cords annually. The available data for current removals on the same lands show roughly 64,000 cords for a 1-year period.[2] This indicates that current cutting levels of aspen type on state-owned land are approximately 165,000 cords short of the potential cut. Figure 3 shows the historical trend of aspen removals on all ownerships in comparison with birch and miscellaneous hardwood types. These non-aspen types are also acceptable in the manufacture of waferboard. This observation, coupled with the desirability of balancing age classes and the fact that the category here (aspen type, state ownership) is just a portion of the resource potential (see table 3), would indicate that opportunities do exist for more intensive management of the forest resource.

Sustainability Concerns

Sizeable investment in a business will not occur if availability of the required raw material cannot be ensured in the long run. One may ask in this example, then, whether an additional 165,000 cords of aspen type can be cut annually on state-owned land over a long enough period to sustain a given wood products industry and at the same time be acceptable to the public.

To enlarge the resource base, the test case was expanded to include aspen lands in county and private industry ownership. Again utilizing the 1977 inventory data for Survey Unit 1, a volume regulation model was chosen to determine a sustainable cutting level over time. Based on a method developed by Barnes (1951) and modified by Rose and Burk (1980) for determining an initial estimate of allowable cut, the iterative process (tabular check) was

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[2] *Timber sales data (by permits) during fiscal year 1977-1978, Region 1, State of Minnesota Department of Natural Resources, Division of Forestry, St. Paul, Minnesota.*

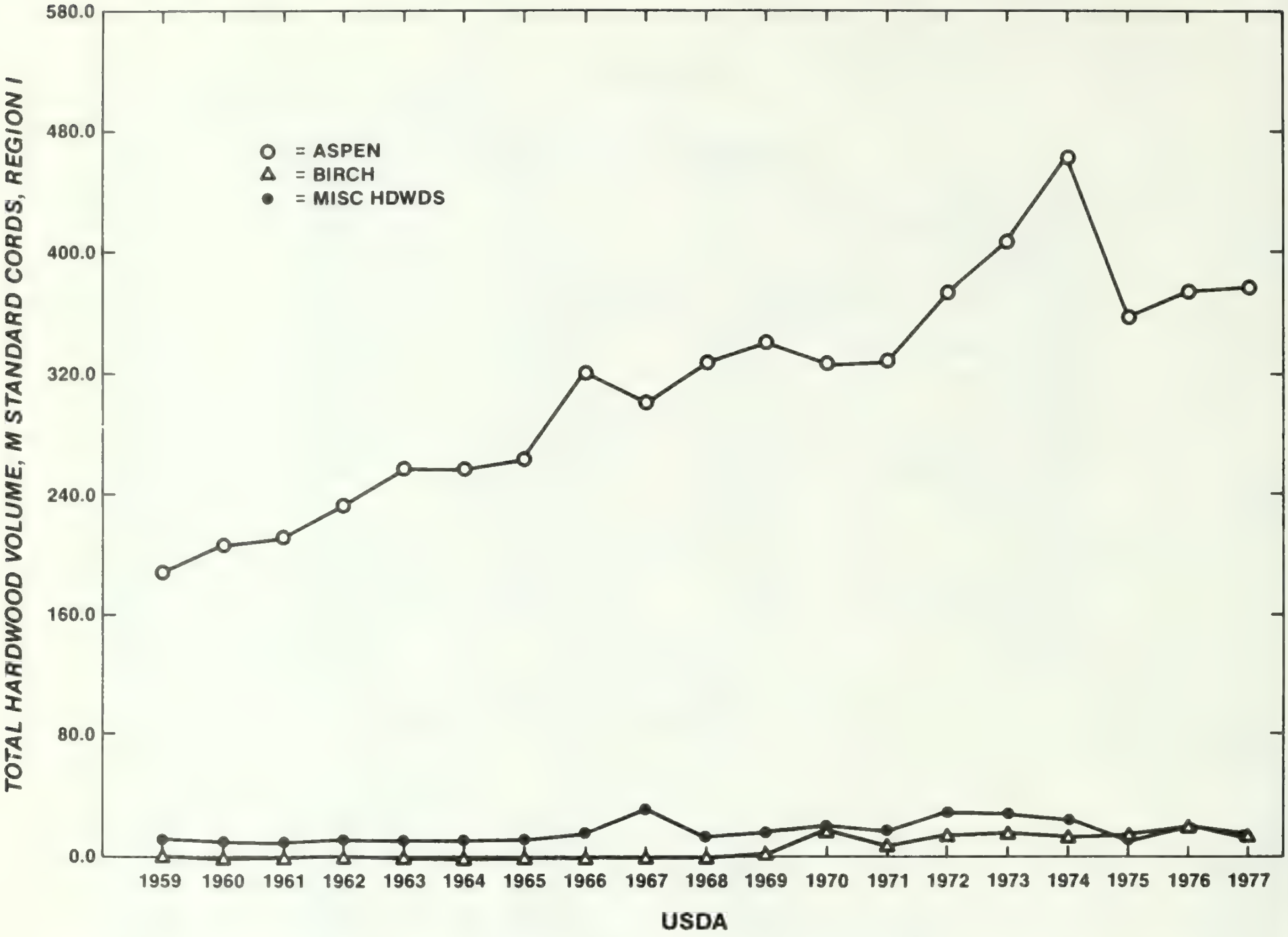

Figure 3. *Pulpwood production for USDA Forest Survey Region 1 from 1959 to 1977, all ownerships.*

carried out to the point where the entire inventory of a stand was cut once in one rotation. The model was applied to the aspen cover type, this time on State, county, and forest industry inventory plots. The allowable cut priorities in the model were the oldest stands first, with those on the best sites receiving top priority.

The imbalance of the age classes in the present aspen stands in northeastern Minnesota is obvious (fig. 4). This highlights the problems to be encountered in the future when set volumes are needed and deficits may occur. Through regulation, a gradual trend toward even-aged management can be achieved (figs. 4-6). Figure 5 shows this nearly accomplished after roughly one rotation (70 years). The simulation shows growing stock volume inventories (fig. 7) declining over the first 20 years and gradually rising to a higher, more stable equilibrium level. The allowable cut (fig. 8) rises rapidly over the first 30 years, eventually leveling off to greater than 550,000 cords per year on aspen cover type alone. This long-run sustainable yield level is more than 150,000 cords above current consumption (fig. 3).

Additional volumes are available from other hardwood cover types, such as birch (table 5), but lack of appropriate stand growth models prevented analysis of long-term sustainable yields of these hardwoods. Another estimate of their potential available volume can be obtained, however, from comparing current growth with current utilization. Net annual growth of all hardwoods excluding aspen is almost 290,000 cords annually (Spencer and Ostrom 1979), while only a fraction of this annual growth is currently being utilized (fig. 3).

All surplus volumes are based on conventional volume measurements. If total tree harvest were implemented, an additional 30 percent of volume could be added to all the stated surplus figures. The same percentage of extra biomass could potentially also

Table 3.—*Hardwood inventory summary for Region 1, by ownership*

	Cover type	State	County	Forest industry	All
Acreage	Aspen	257,065	475,222	209,078	1,562,053
	Aspen>50 yrs.	86,641	119,395	57,178	430,942
	Other hardwoods	168,839	313,718	110,298	1,031,746
	All hardwoods	425,904	788,940	319,376	2,593,799
Merchantable volume (Cords)	Aspen	3,089,183	5,267,157	2,384,874	16,517,283
	Aspen>50 yrs.	1,513,407	1,819,415	1,019,717	6,682,647
	Other hardwoods	1,997,062	3,641,195	1,138,346	11,388,416
	All hardwoods	5,086,245	8,908,352	3,523,220	27,905,699
Harvestable biomass (Green tons)	Aspen	9,574,338	16,659,387	7,484,716	52,258,621
	Aspen>50 yrs.	4,637,238	5,789,155	3,200,445	20,883,598
	Other hardwoods	6,532,225	12,156,842	3,900,162	37,997,587
	All hardwoods	16,106,593	28,816,229	11,384,878	90,256,208
BTU's x 10^6 Based on harvestable biomass	Aspen	92,200,874	160,429,899	72,077,817	503,250,522
	Aspen>50 yrs.	44,656,621	55,749,589	30,820,305	201,109,077
	Other hardwoods	69,856,622	133,762,229	42,264,839	416,687,217
	All hardwoods	162,057,496	294,192,128	114,342,656	919,937,739
Megawatt years Based on harvestable biomass	Aspen	832	1,449	651	4,421
	Aspen>50 yrs.	400	502	276	1,751
	Other hardwoods	632	1,208	382	3,689
	All hardwoods	1,464	2,657	1,033	8,110
Residual harvestable biomass (Green tons)	Aspen	2,623,676	4,808,284	2,118,750	15,094,734
	Aspen>50 yrs.	1,232,072	1,695,471	906,082	5,847,642
	Other hardwoods	1,739,307	3,417,974	1,168,132	10,665,389
	All hardwoods	3,899,605	7,436,184	2,929,150	23,282,530
BTU's x 10^6 Based on residual harvestable biomass	Aspen	25,271,247	46,313,392	20,407,800	145,392,478
	Aspen>50 yrs.	11,867,318	16,330,777	8,727,328	56,324,488
	Other hardwoods	18,262,713	35,888,727	12,265,386	111,986,679
	All hardwoods	85,805,247	78,079,932	30,756,075	244,466,565

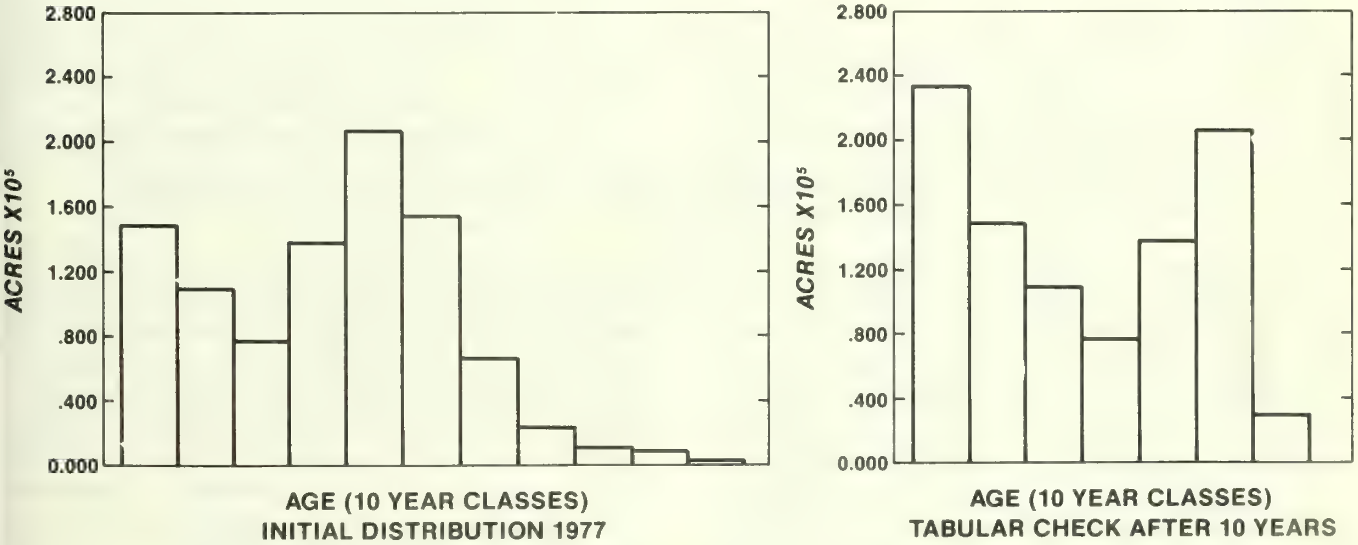

Figure 4.—*Initial (1977) age class distribution for the aspen cover type on State, county, and forest industry land in Region 1, and distribution after 10 years of volume regulation.*

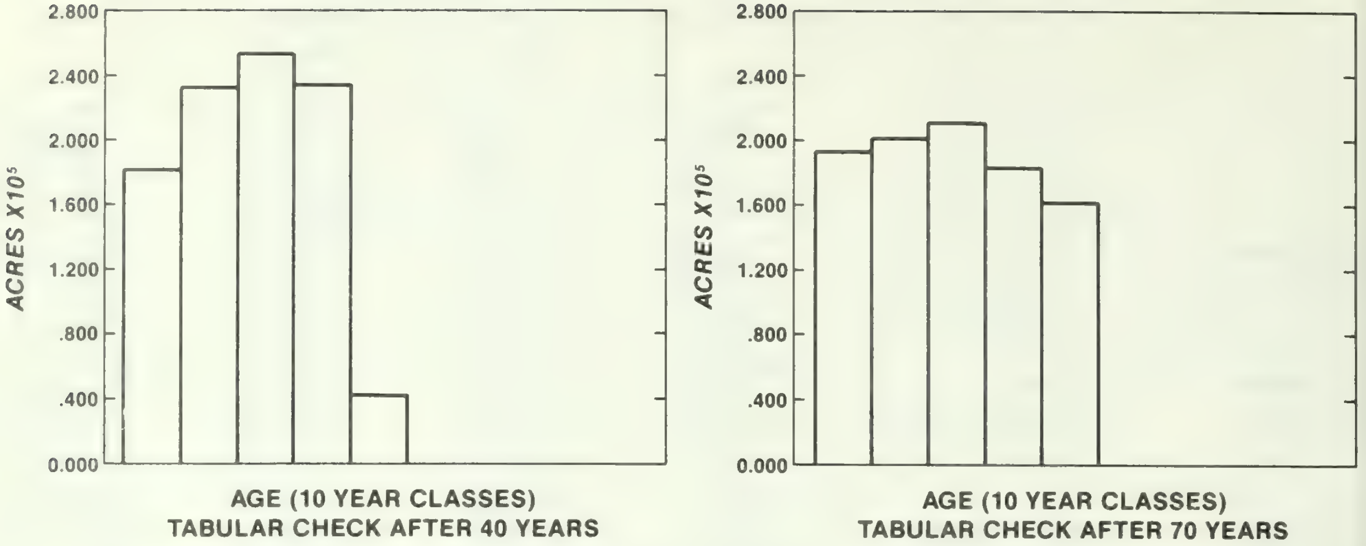

Figure 5.—*Age class distribution for the aspen cover type on State, county, and forest industry land in Region 1 after 40 and 70 years of volume regulation.*

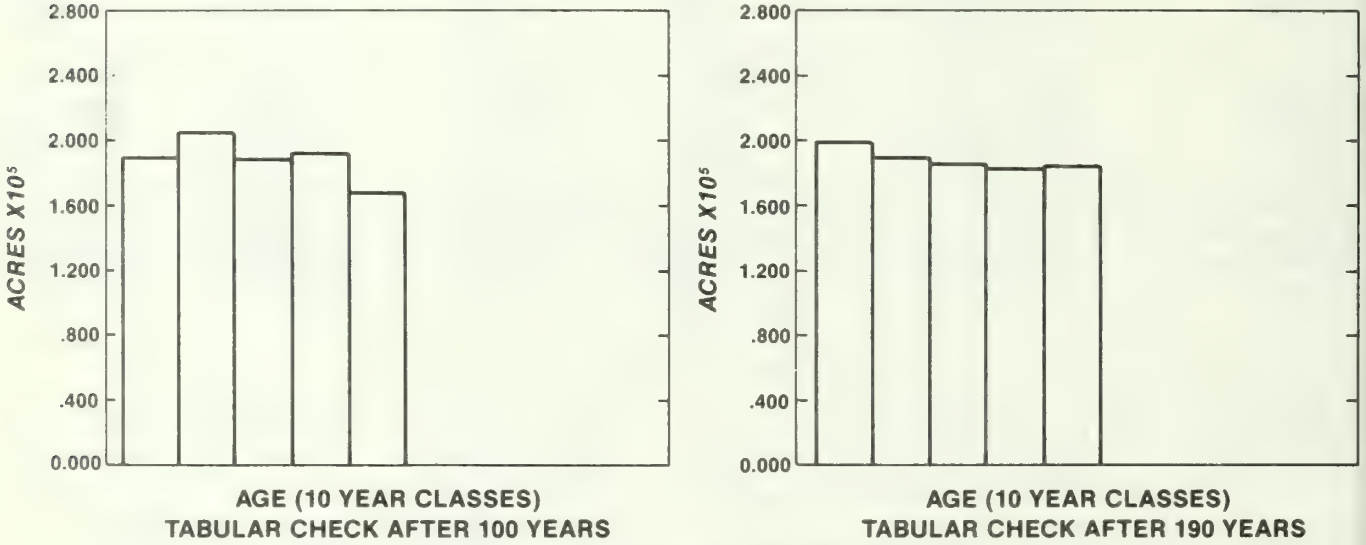

Figure 6.—*Age class distribution for the aspen cover type on State, county, and forest industry land in Region 1 after 100 and 190 years of volume regulation.*

be removed from timber stands currently being harvested and not considered surplus in our analysis. Thus, the potential for forest industry expansion in Survey Unit 1 appears to be substantial.

Linkage Between Models

At this point, the growth projection has indicated biological opportunities for increased timber harvests. The output is expressed in cord volumes by cover type. To determine the economic impacts of such increases on the region, these values must be incorporated into the regional economic impact forecasting system, which would show how an expanded timber industry based on these timber volumes would affect the various sectors of a region's economy. Lundgren and Essex (1979) have shown the interrelatedness of major components (fig. 9) of a timber resource evaluation program designed to investigate economic impacts. Based on management alternatives, these economic impacts are the basis for future plans and programs. A scenario of industrial expansion can be devised in which the timber harvest volume indicated by the resource evaluation system is

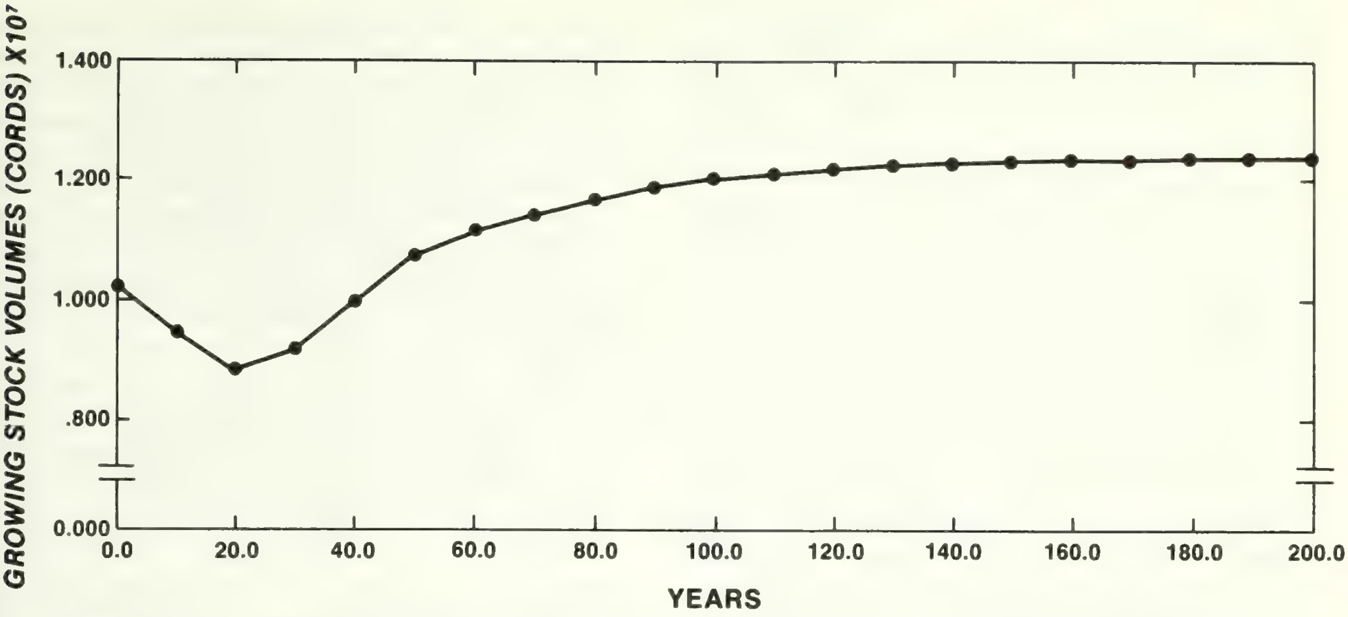

Figure 7.—*Total growing stock volumes for the aspen cover type on State, county, and forest industry land in Region 1 under volume regulation.*

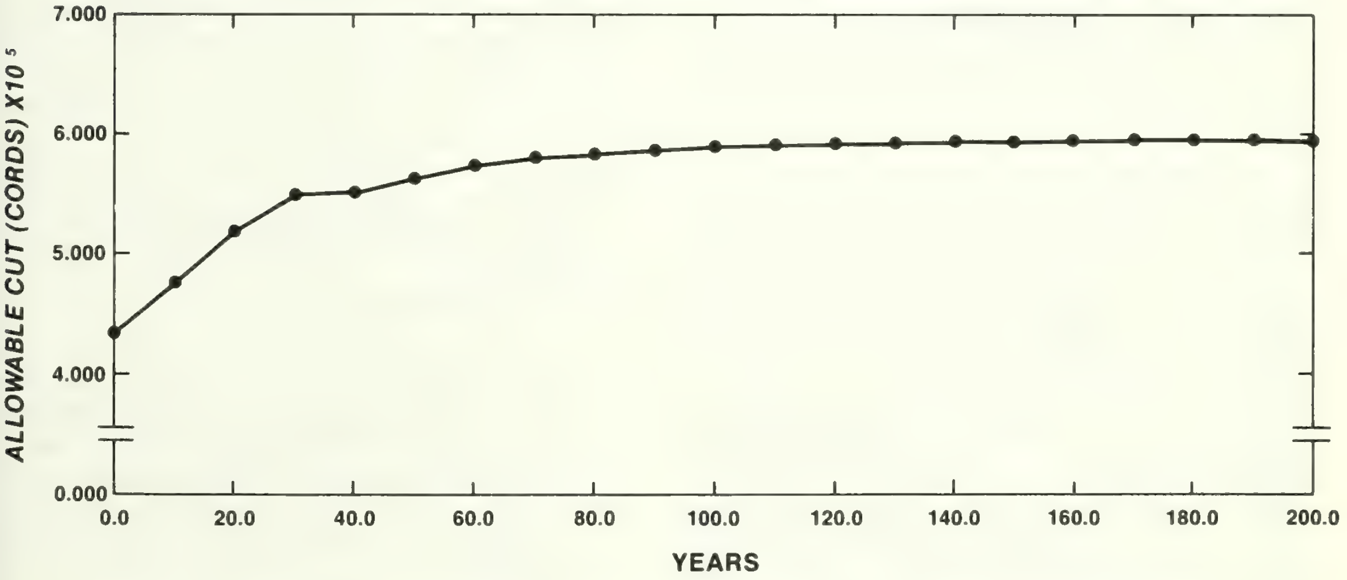

Figure 8.—*Allowable cut volumes for the aspen cover type on State, county, and forest industry land in Region 1 under volume regulation.*

utilized. The scenario is the link that transforms cord volumes into associated employment and sector expansion—the socioeconomic variables of interest.

Scenario Development

To maintain a realistic scenario of expanded industrial development, it was necessary to investigate potential markets. Although aspen is an important species for pulpwood in the Lake States, the aspen resource has suddenly found an expanded use in the waferboard industry. Largely coincidental to this study, announcements began cropping up of studies to determine plant locations and of planned groundbreaking ceremonies (Duluth News-Tribune 1978, 1979a; Minneapolis Tribune 1979). Even the one producing waferboard plant in the United States announced its expansion in Grand Rapids, Minnesota (Duluth News-Tribune 1979b).

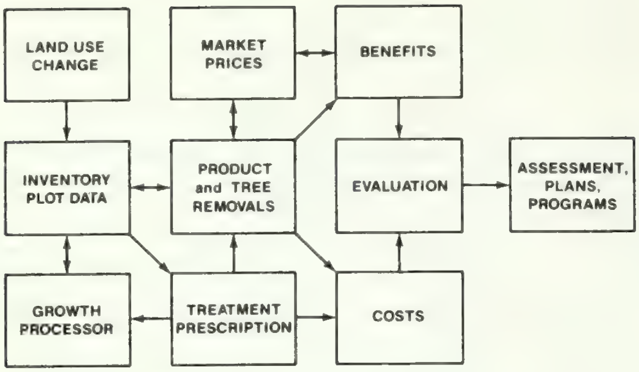

Figure 9.—*Major components of a timber resource evaluation system for economic analysis (Lundgren and Essex 1979).*

The logical industry had appeared and showed promise for the future. It has been predicted that the average variable costs of Minnesota waferboard, a product that competes favorably with plywood, will remain at 57 to 58 percent of southern plywood costs and 51 to 54 percent of western plywood costs through 1985 (Fuller and Veltkamp 1979). Another possible user of the harvested biomass could come in the form of a wood-fired electrical generation plant, an interim measure to help meet regional energy needs (Rose and Olson 1979).

The initial plan was to determine the economic impacts of just one new facility within the region. However, it was later determined that because the data base used for the economic projection included three counties outside of Survey Unit 1, the impact of one such facility would have a minor impact on an area of this size. Many land-use planners have observed political boundaries overlapping economic development boundaries, as is the case here. Douglas County, Wisconsin, is intimately associated economically with the Duluth area (St. Louis County, Minnesota); the other two Counties included in the regional impact study are Itasca and Aitkin in Minnesota.

To demonstrate economic impacts over a region of this size it was necessary to consider more than one new industrial facility. Thus, the scenario of development assumed introduction, over a 10-year period, of four waferboard plants and one electrical generation plant fired by wood. A facility would be introduced every 2 years, the first one beginning construction in 1980 and the last one opening on January 1, 1990. The plant locations are not site-specific; they must only lie within the economic development region boundaries. Each type of industrial facility has its own input requirements. These inputs include not only wood as a raw material, but also the construction, labor, and capital investment needed to bring the facility into operation. All must be addressed, as they may or may not influence the regional economy. The exact development schedule (fig. 10) and the specific input requirements for the economic evaluation simulated via SIMLAB are detailed in the following sections.

Year	**Industrial activity**	**Facility opening**
1980 1981	Construction of waferboard plant #1—approximately 2 years	
1982	Construction of 25 MW wood-fired electrical generation plant—approximately 2 years	WAFERBOARD PLANT #1 opens January 1, 1982, averaging ½ of full production in 1982.
1983		Waferboard Plant #1 at full production in 1983.
1984	Construction of waferboard plant #2—approximately 2 years	POWER PLANT opens January 1, 1984.
1985		
1986	Construction of waferboard plant #3—approximately 2 years	WAFERBOARD PLANT #2 opens January 1, 1986, averaging ½ of full production in 1986.
1987		Waferboard Plant #2 at full production in 1987.
1988	Construction of waferboard plant #4—approximately 2 years	WAFERBOARD PLANT #3 opens January 1, 1988, averaging ½ of full production in 1988.
1989		Waferboard Plant #3 at full production in 1989.
1990	No further industrial expansion	WAFERBOARD PLANT #4 opens January 1, 1990, averaging ½ of full production in 1990.
2000	End of projection, December 31.	Waferboard Plant #4 at full production in 1991, as are others to year 2000.

Figure 10.—*Timetable for industry expansion over a 10-year period.*

Waferboard Plant

"Structural grade particle board," "flakeboard," or waferboard," basically refer to the same type of roduct. The difference lies in the actual chip used n the manufacturing process and the grain direction n the chip—i.e., the way it is cut from the log. Wafrboard uses a "wafer" that is large and square with he grain parallel to the plane of the cut. This is ccomplished by feeding the log in sideways and hipping it from the side, rather than feeding the utt of the log into the chipping drum (Vajda 1978). Consequently, roundwood must be delivered to the lant and chipped, rather than being chipped at the anding. Hence, whole tree chipping in the woods for waferboard product cannot be done with current echnology.

With introduction of a new waferboard facility, onstruction activity, increased gross output in the ood products sector, increased transportation via ruck freight to haul the product, and expanded outut in the logging sector would all combine to create obs and increase the cash flow in the region. Changes n these four sectors become inputs for the SIMLAB rojection.

Construction

The announced costs of a plant producing 150 mm o 170 mm ft^2 (⅜-inch thick basis) range from $30 nillion to $37 million in current dollars (Minneaplis Tribune 1979). An average of $32.5 million was sed in this example for the capital costs of a plant roducing 150 mm ft^2 (⅜-inch thick basis) per year. This figure includes imported capital (equipment) ot available in the region, in addition to the costs f construction. Because equipment must be purhased, in most cases, outside the State, it must be xcluded from the economic impact assessment. The eason, of course, is that the money expended will ot flow into northeastern Minnesota. The percentge of the total capital costs spent on equipment is izeable—55 percent is used here (Stearns-Roger Corporation 1970). Hence, actual regional construcion costs are:

Capital costs (1979 dollars)	$32.5 million
Less 55 percent supplied from outside northeastern Minnesota	$17.88 million
Regional construction costs	$14.63 million

All costs are expressed in 1970 dollars for the base ear data in SIMLAB. Using the Consumer Price Index (CPI) as a deflator, this cost becomes $5.58 million in 1970. Plant construction proceeds over a 23-month period, hence this figure is divided equally to represent a yearly expenditure.

Wood products sector output

The new industry adds a gross output by selling its product in the marketplace. The gross value was estimated in this example by obtaining the current retail price per unit of the product in the Minneapolis-St. Paul market area, then stripping back to a wholesale price, FOB at the mill. This was done by using cost-of-doing-business ratios for retail and wholesale margin determination, and finally subtracting out an estimated cost per unit for transportation. The Appendix shows the procedure and calculations in detail. Again using the CPI as a deflator, the value of gross output becomes $2.34/ft^3 in 1970 terms or $73.125/M ft^2 (3/8-inch thick basis).

The first year of operation for each plant assumes only 50 percent of full production. By the second year, efficiencies of manpower and equipment allow for full production at 150 MM ft^2.

Transportation sector output

With the advent of the new product, some sort of increased activity will occur in the freight sector. The only presently operating waferboard plant in Minnesota (Grand Rapids) utilizes contract trucking to deliver its product to market. The scenario devised here assumes the Twin Cities to be the delivery point (for further distribution). Estimates of trucking rates were based on those charged the current waferboard manufacturing company (Grand Rapids to the Twin Cities);[3] the rates were inflated linearly to roughly represent the distance from Virginia, Minnesota, to the Twin Cities. Because this study does not specify plant locations, Virginia, due to its central location in the region, was selected as an average.

The value, then, is expressed per unit output. In 1979 dollars, it equates to $0.28/ft^3 of waferboard produced (1,000 ft^3 = 32,000 ft^2 on a ⅜-inch thick basis). In the first year of operation (i.e., 50 percent of full production), output in the transportation sector is $347,867 in 1970 dollars and twice that amount when full production is reached.

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[3] *Personal communication, Mr. Eldon Keehr, Intrastate tariffs, Minnesota Department of Transportation, November 5, 1979.*

Logging sector output

Input requirements (i.e., cord volumes) per unit output had to be determined to get an estimate of gross output for the logging sector of the economy. By then assigning the average price for a delivered cord of aspen, a rough estimate could be made. The average price for aspen at the time of this simulation was \$26/cord, delivered (Minneapolis Tribune 1979). The input requirement, cords/M ft^2 (3/8-inch thick basis), was obtained two ways. Rough quoted estimates of cords consumed per year by a waferboard plant of the same size placed the figure around 780 cords/MM ft^2 (Fuller and Veltkamp 1979). Using a transformation formula for flakeboard (1,235 kg dry wood input per ton output), an estimate of 771 cords/MM ft^2 was obtained (Vajda 1975). For this study, then, 800 cords/MM ft^2 (3/8-inch thick basis) was used as the waferboard input requirement estimate.

25 MW Wood-fired Power Plant

The only differences in terms of sector changes for a new power facility versus a waferboard plant are a different intensity of construction, additional gross output in the electric utility sector, and a different wood requirement per unit output. The transportation sector is not noticeably influenced by the new plant, although nearly all sectors of the economy will reflect some change resulting from industrial expansion. This will be discussed further in the impact assessment section.

Construction

Plant construction costs for a 25 MW wood-fired power facility were estimated at \$8,611,000 in 1973 dollars (Stearns-Roger Corporation 1970). Equipment costs were estimated to be 57 percent of this figure, leaving \$2,814,790 in 1970 dollars. Based on a 20-month development schedule, this figure would be divided in half, as were the waferboard plant costs, to represent an annual expenditure over 2 years.

Electric utility sector output

Gross output was based on the assumption that the power plant would run 365 days a year, 24 hours a day. It was further assumed the plant would generate, on the average, at 80 percent of full capacity. Rates in effect in 1970 for residential usage were obtained from past records.[4] The gross output in 1970, then, is:

$$25 \text{ MW} \times 0.80 \text{ (percent load)} \times 8{,}760 \text{ hrs/yr} \times \$0.028 \text{ KWhr} \times 1{,}000 \frac{\text{KW}}{\text{MW}} = \$4{,}905{,}600.$$

Logging sector output

Wood requirements at full load were found to be 106,775 cords/year (Olson 1978). At 80 percent of capacity, roughly 85,000 cords are required. This is the input value used in this study. Actually, a plant could get by with less, as all biomass is burned (i.e., whole tree harvesting). This reduction could be as much as 45 percent.

In view of the development scenario, timber volume requirements are summarized by year through the projection period (table 4). Also shown is the value of the output in this sector, using the \$26/cord present worth deflated by the CPI to 1970. Although it is not input into the SIMLAB projection, man-hours per year required to carry out the corresponding annual harvest is also indicated. This is based on a 0.89 cords/man-hour estimate (Biltonen *et al.* 1976) that includes all workers involved in such a full-time harvesting system. It is included to indicate the magnitude by which jobs may be increased by accelerating timber harvest activities. The input-output model uses its own transaction coefficients to determine changes in the other sectors.

Adjustments to Transportation and Logging Sector Outputs

The wood products sector (gross output) and to a lesser extent the electrical products sector are the main driving forces for economic changes in this scenario. In both instances, these industries are relatively new. Because SIMLAB uses an input-output analysis based on historical industry transaction information, it is not as sensitive to inter-industry transactions given the new industry component. For example, the input-output ratio (i.e., transaction coefficient) representing the amount purchased from the logging sector in order to produce \$1 of product by the wood products industry was too low. The model did not adequately account for total purchases—timber input—required to make the waferboard or electrical products. This was also true of the transportation sector output. Consequently, the transportation

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[4] *Personal communication, Ms. Elizabeth Dupay, Rates Department, Northern States Power. November 12, 1979.*

Table 4.—*Cord requirements for development scenario by year with associated gross output for the logging sector and man-hours/year required for harvest operation.*

Year	Timber requirements	Gross output in logging sector	Man-hours/year[1]
	Cords	*1970 million dollars*	*Thousand*
1980			
1981	120,000	1.65	107
1982	120,000	1.65	107
1983	205,000	2.83	183
1984	205,000	2.83	183
1985	325,000	4.48	290
1986	325,000	4.48	290
1987	445,000	6.13	397
1988	445,000	6.13	397
1989	565,000	7.79	505
1990	565,000	7.79	505
	yearly to 2000	yearly to 2000	yearly to 2000
2000			

[1] Assumed: 2,000 man-hours/year average, hence 1990 figure translates into approximately 253 man-years of employment.

and logging sector figures were adjusted to show those increases in gross output that the model did not account for internally.

The Appendix includes an example showing how these adjustments were made. Table 5 cites the values by sector and year used as inputs to modify the economy of the study region in the SIMLAB test projection.

Projection Results

According to the schedule, changes were made to the study area's economy corresponding to industrial development. Industrial classifications were broken down into sectors for the test projections (table 6). The baseline projection represents events as they would evolve in the absence of timber industry expansion. The development projection is compared against this and any deviation from the baseline noted. Based on the development scenario, the changes in final demand (table 5) were made in the appropriate years of the projection. The construction, logging, wood products, truck transportation, and electrical service sectors (i.e., sectors 12, 15, 16, 35, and 38, respectively) were those incurring the simulated direct economic activity. The total variable effect (e.g., employment), as represented in tables 7-11, is the sum of the values for the baseline and the development impact deviation. Five of the program output tables (total population, total employment, gross output, total earnings from wages and salaries, and totals in capital stock investment) were summarized and are discussed next.

Table 5.—*Scenario input to modify economy of test region by sector and year*

(In 1970 dollars)

Year	Activity	Construction costs	Wood products sector output	Electrical product sector output	Adjusted transportation sector output	Adjusted logging sector output
1970		(0)	(0)	(0)	(0)	(0)
1980	(Construction waferboard plant #1)	2,790,000				
1981		2,790,000	5,484,000			
1982	Waferboard plant #1 opens 1/1/82	1,407,000	10,969,000		332,283	616,590
1983	(Construction power plant)	1,407,000	10,969,000		664,568	762,991
1984	Power plant opens 1/1/84	2,790,000	10,969,000	4,906,000 yearly to 2000	664,568	762,991
1985	(Construction waferboard plant #2)	2,790,000	16,453,000		664,568	2,412,991
1986	Waferboard plant #2 opens 1/1/86	2,790,000	21,938,000		996,846	1,379,580
1987	(Construction waferboard plant #3)	2,790,000	27,422,000		1,328,126	1,995,981
1988	Waferboard plant #3 opens 1/1/88	2,790,000	32,906,000		1,660,409	962,571
1989	(Construction waferboard plant #4)	2,790,000	38,391,000		1,992,691	1,589,161
1990	Waferboard plant #4 opens 1/1/90	(0)	43,875,000		2,324,971	555,562
1991	No additional industrial development		(43,875,000 yearly to 2000)		(2,657,254 yearly to 2000)	(0 yearly to 2000)
2000	End projection					

Table 6.—*Breakdown of test region economic sectors, SIMLAB*

Sector number	Sector names
1	Livestock and livestock production
2	Other agricultural production
3	Peatland production (empty)
4	Agricultural services, forestry[1] and fisheries services and products
5	Iron and ferrous alloy ores
6	Other metal ores except copper
7	Copper ore mining except Minnesota
8	Open pit copper ore mining, Minnesota
9	Deep shaft copper ore, Minnesota
10	Nonmetal mining
11	Agricultural chemicals
12	Contract construction
13	Food and kindred products
14	Apparel and miscellaneous fabrics, textiles
15	Logging camps, sawmills
16	Other lumber and wood products
17	Paper and allied products
18	Printing, publishing, and allied industries
19	Chemicals
20	Peat-chemicals (empty)
21	Petroleum refining and related industries
22	Rubber and miscellaneous plastic products
23	Stone and clay products
24	Primary iron and steel industries
25	Primary copper industries
26	Copper rolling and drawing industries
27	Other 1° metals rolling and drawing industries
28	Fabricated metal products
29	Machinery, except electrical
30	Electrical machinery
31	Miscellaneous manufacturing
32	Transportation, except following
33	Railroad transportation
34	Highway passenger transportation
35	Truck transportation and warehousing
36	Air transportation
37	Communication
38	Electric service
39	Gas service
40	Water service
41	Wholesale trade
42	Retail trade
43	Finance and insurance
44	Real estate and rental
45	Hotels, personal and repair services
46	Business services
47	Automobile repair and service
48	Amusements
49	Medical, educational, and nonprofit organizations
50	Federal government enterprises
51	State and local enterprises
52	Other industry
53	Other government (public goods and services)

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[1] Industries engaged primarily in operation of timber tracts, nurseries, and forest services (fire protection).

Total population

Table 7 shows the total population by age groups through year 2000. The development impact on population in 1985, 1992, and 2000 is positive, as would be expected. The largest impact falls in the group between 25 and 34 years of age. It should be pointed out, though, that these population projections reflect more than the result of industrial expansion. They also reflect a decreasing population, which can be seen by viewing only the baseline projection. The reason for this downward trend is decreasing employment in taconite mining and manufacturing beyond the mid-1980's (Meagher *et al.* 1979). The "increase" in population due to the timber-based expansion only slightly offsets this baseline decrease. Population in the study area for the year 2000 is estimated at 334,071 for the development projection, compared with 325,571 for the baseline case.

Total employment

Neither of the two new industries involved in the development scenario is particularly labor-intensive. Nevertheless, they have far-reaching effects throughout the economy. Table 8 represents the status quo employment projections in the baseline run, in addition to employment effects, by sector, as a result of increased economic activity. As expected, employment in the logging and wood products sectors (15 and 16) shows noticeable increases with respect to the other sectors. This is especially true in 1985 and 1992. Even more interesting, though, are the sizeable increases in the service sectors of wholesale and retail trade (41 and 42), and the medical, educational, and nonprofit organizations (49). Combined with the "other government" sector (53), which represents the traditional bureaucratic levels of Federal, State, and local agencies, these four groups constitute nearly 59 percent of the total employment increases attributed to the industrial development in year 2000. In that year, the four sectors that were altered in the development case only contribute approximately 24 percent to the total employment increase of 4,495 persons. Additionally, they also show a decline in total numbers from 1992. Compared with the base year of 1977, total employment decreased 4.6 percent by 2000 in the development case, compared with 7.8 percent in the baseline projection. It is more likely that industrial growth picked up unemployed personnel in the region, rather than causing an immigration of workers from outside the study area.

Table 7.—*Estimated and projected total population by age groups, northeastern Minnesota and Douglas County, Wisconsin, 1977-2000*

Age group	1977 Baseline	1985 Baseline	1985 Development impact	1992 Baseline	1992 Development impact	2000 Baseline	2000 Development impact
1-5	36,110	39,894	35	33,043	476	25,069	1,238
6-11	45,743	44,767	97	49,233	383	39,472	1,020
14-17	32,776	17,918	56	19,852	270	23,089	391
18-24	49,776	36,783	193	25,163	715	30,509	922
25-34	53,275	66,518	180	53,192	1,260	30,569	2,409
35-54	81,672	81,302	112	95,550	606	106,817	1,770
55-64	40,880	35,220	36	31,357	188	31,427	368
65 +	43,721	43,816	42	41,875	207	38,620	383
Column total	383,954	366,218	749	349,266	4,104	325,571	8,500
Grand total	383,954	366,967		353,370		334,071	

Table 8.—*Estimated and projected total employment, northeastern Minnesota and Douglas County, Wisconsin, 1977-2000*

(In number of persons employed)

Number	Industry title[1]	1977 Baseline	1985 Baseline	1985 Development impact	1992 Baseline	1992 Development impact	2000 Baseline	2000 Development impact
1	Livestock	2,116	1,593	—	1,657	15	1,442	17
2	Other agric.	1,503	1,226	—	1,144	19	996	19
4	Agric., for., fish. serv.	775	930	24	1,069	74	1,264	74
12	Construction	3,992	4,222	84	4,025	43	4,163	45
13	Food, kindred products	3,464	3,132	—	2,849	15	2,646	23
15	Logging, sawmills	1,273	1,206	46	1,158	104	1,128	87
16	Other lumb., wood prod.	833	841	259	837	874	859	747
17	Paper, allied prod.	5,599	5,753	8	5,749	26	5,942	26
21	Petroleum refin.	399	320	—	257	6	212	7
29	Machinery, exc. elect.	608	683	15	687	27	784	17
32	Transport, except:	1,947	1,679	6	1,312	14	1,052	11
33	Rail transport	2,326	2,091	17	1,857	39	1,684	35
35	Truck transport	838	838	39	848	136	885	129
37	Communication	1,215	995	52	795	22	652	26
38	Electric	1,145	981	66	864	59	789	49
41	Wholesale trade	7,587	7,481	79	6,952	218	6,721	237
42	Retail trade	30,573	30,167	174	27,787	733	26,434	1,144
49	Medical, educ. org.	13,876	13,207	21	11,940	96	10,727	178
50	Fed. enterprises	918	967	13	985	28	1,031	39
53	Other government	22,993	23,571	146	23,436	592	23,372	1,079
Column total		103,980	101,883	1,049	96,208	3,140	92,783	3,989
Total (all 53 sectors)		138,750	136,580	1,183	130,908	3,504	127,920	4,495
Grand total		138,750	137,763		134,412		132,415	

[1] See table 6 for complete titles.

Gross output

The value of production in producer's prices—gross output—is used as a measure of region's business volume. Industries within the region buy goods and services from other industries to stay in operation. Workers spend their payrolls also to buy goods and services. Table 9 shows the value of gross output by sector for the baseline and the development cases. In the year 2000, timber-based sectors 15 and 16 together represent 35 percent of the total increase in gross output (above the baseline), valued at $178,970,000. Compared with 1977, the baseline projection to year 2000 indicates a 53 percent increase in gross output. With industrial growth, the

Table 9.—*Estimated and projected value of gross output, northeastern Minnesota and Douglas County, Wisconsin, 1977-2000*

(In thousands of 1970 dollars)

			1985		1992		2000	
Number	**Industry title**[1]	**1977 Baseline**	**Baseline**	**Development impact**	**Baseline**	**Development impact**	**Baseline**	**Development impact**
1	Livestock	48,153	48,153	—	63,904	569	70,865	855
2	Other agric.	24,049	25,364	—	29,995	503	33,067	634
4	Agric., for., fish. serv.	20,151	24,520	636	27,788	1,909	32,342	1,876
12	Construction	132,037	153,861	3,035	156,896	1,676	172,901	1,849
13	Food, kindred products	319,507	364,048	340	401,311	2,041	450,968	3,987
15	Logging, sawmills	92,349	115,057	4,395	133,363	12,828	158,370	12,221
16	Other lumb., wood prod.	34,954	42,318	13,539	48,359	50,478	56,857	49,494
17	Paper, allied prod.	227,799	297,191	437	361,938	1,596	455,133	2,018
21	Petroleum refin.	58,860	64,805	525	69,792	1,621	77,136	
29	Machinery, exc. elect.	21,397	28,799	637	33,479	1,313	44,071	962
32	Transport, except:	94,416	111,900	411	128,656	1,385	151,717	1,568
33	Rail transport	67,859	79,115	638	87,223	1,866	98,091	2,032
35	Truck transport	15,988	18,161	860	20,076	3,205	22,822	3,330
37	Communication	31,784	34,891	274	36,729	1,034	39,640	1,566
38	Electric	85,765	95,938	6,522	109,840	7,563	130,141	8,193
41	Wholesale trade	160,085	185,601	1,935	204,699	6,408	233,364	8,232
42	Retail trade	260,396	294,282	1,698	310,907	8,210	338,318	14,648
49	Medical, educ. org.	187,782	197,238	316	193,561	1,545	188,376	3,130
50	Fed. enterprises	14,259	15,430	218	16,298	460	17,607	660
53	Other government	539,017	662,565	4,105	760,922	19,205	874,976	40,385
Column total		2,436,608	2,859,239	40,522	3,195,736	125,414	3,646,765	160,002
Total (all 53 sectors)		3,626,672	4,220,464	46,138	4,782,795	139,009	5,561,805	178,970
Grand total		3,626,672	4,266,602		4,921,805		5,740,775	

[1] See table 6 for complete titles.

development impact would reflect a 58 percent increase over the same period. Once again, wholesale and retail trade increases are high (13 percent of total) in year 2000, spurred by consumer spending. Government growth, in response to increased economic activity, takes second place to the wood products sector gross output (23 percent of total).

Total earnings

The trend in total earnings from wages and salaries paid (table 10) follows that of gross output. With development, total earnings increase 32 percent from 1977 to year 2000, compared with a 28 percent increase in the baseline projection over the same period. Once again, the wood products sector shows the largest increase, followed by the governmental sector and the wholesale-retail trades. Construction earnings fall off by nearly 50 percent after the development of new industrial facilities is completed in 1990. The construction of residential housing, service facilities, etc., constitutes earnings thereafter.

Capital stock

The totals of all annual investments, both for output increases and pollution abatement (less depreciation), are shown in table 11. Industries that are less labor-intensive show higher values of capital stock, representing heavy investment in machinery and pollution abatement equipment. This can be seen in the development run, year 2000, where the electrical sector has the greatest increase, due to extremely costly air pollution control equipment for the new electrical plant. The baseline projection indicates a 54 percent increase in total capital stock over the period, valued at $3,695,819,500 in the year 2000. This is in contrast to a 57 percent increase, totaling $3,763,305,200 at the end of the projection, for the industry expansion projection. It should be noted that the government (public) sector (53) is not viewed as one that accumulates capital stock in the same sense that the private industrial sectors do.

Table 10.—*Estimated and projected total earnings from wages and salaries of employed work force, northeastern Minnesota and Douglas County, Wisconsin, 1977-2000*

(In thousands of 1970 dollars)

Number	Industry title[1]	1977 Baseline	1985 Baseline	1985 Development impact	1992 Baseline	1992 Development impact	2000 Baseline	2000 Development impact
1	Livestock	15,483	11,653	—	12,122	108	10,551	127
2	Other agric.	10,248	9,742	—	9,086	152	7,911	152
4	Agric., for., fish. serv.	6,144	7,597	—	8,731	600	10,326	599
12	Construction	55,028	68,626	1,354	66,798	713	73,363	784
13	Food, kindred products	22,227	23,849	—	25,507	128	28,321	250
15	Logging, sawmills	6,766	8,064	308	9,626	926	11,897	918
16	Other lumb., wood prod.	4,430	5,621	1,798	6,997	7,304	9,058	7,885
17	Paper, allied prod.	41,811	51,281	75	60,414	266	74,514	330
21	Petroleum refin.	5,843	5,967	48	5,670	132	5,451	167
29	Machinery, exc. elect.	4,535	5,721	126	6,499	254	8,454	184
32	Transport, except:	18,112	19,068	70	17,969	193	17,570	181
33	Rail transport	28,599	34,883	281	41,809	894	51,595	1,069
35	Truck transport	7,792	9,511	451	11,618	1,855	14,784	2,157
37	Communication	14,350	16,291	128	17,499	493	19,408	767
38	Electric	11,143	10,465	711	10,012	689	10,115	637
41	Wholesale trade	52,127	56,212	586	56,720	1,776	60,664	2,140
42	Retail trade	122,732	132,427	764	132,454	3,498	139,392	6,035
49	Medical, educ. org.	91,170	93,854	150	84,857	677	76,231	1,267
50	Fed. enterprises	8,373	9,533	135	9,716	275	10,169	381
53	Other government	164,643	168,785	1,046	166,999	4,215	166,542	7,687
Column total		691,558	749,152	8,033	761,105	25,151	806,316	33,718
Total (all 53 sectors)		943,668	1,038,015	9,331	1,093,128	27,510	1,203,574	37,331
Grand total		943,668	1,047,345		1,120,639		1,240,905	

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[1] See table 6 for complete titles.

SUMMARY

Minnesota's Survey Unit 1 (fig. 2) was chosen as the study area for determining the potential for increased forest management activities. A 10-year projection of state-owned lands in aspen cover type was made. Management options with and without timber harvesting were used to: (1) compare the effects of no timber harvesting versus appropriate harvesting treatments on age class distributions; and (2) obtain an idea of the timber volumes that could be harvested above current levels.

The no-harvest run showed a perpetuation of unbalanced age class distributions, making the situation even worse in terms of overmature timber. Stand volume decreases in some age classes were attributed to natural losses from such things as insect and disease infestation. The management run called for heavy removals, especially in the older age classes, in an attempt to balance the distribution of age classes. Simulated harvest was approximately 229,000 cords/year, roughly 165,000 cords/year above current levels in this ownership-cover type category. With the inclusion of other underutilized hardwood cover types, such as birch and balsam poplar, the potential harvest opportunity is high.

Sustainability of such an increased harvest was investigated, expanded to state, county, and forest industry ownerships (aspen cover type). The simulation showed that not only could highly unbalanced

Table 11.—*Estimated and projected totals in capital stock, northeastern Minnesota and Douglas County, Wisconsin, 1977-2000*

(In thousands of 1970 dollars)

			1985		1992		2000	
Number	**Industry title**[1]	**1977 Baseline**	**Baseline**	**Development impact**	**Baseline**	**Development impact**	**Baseline**	**Development impact**
1	Livestock	42,243.8	42,243.8	—	57,289.3	450.3	62,110.0	749.7
2	Other agric.	21,098.0	22,251.2	—	26,481.5	439.7	29,008.6	556.4
4	Agric., for., fish. serv.	17,677.8	21,510.4	557.8	24,377.5	1,674.5	28,372.5	1,646.1
12	Construction	145,036.8	145,036.8	—	145,036.8	1,528.9	159,634.0	1,685.9
13	Food, kindred products	68,154.9	77,656.1	—	85,604.8	435.3	96,197.3	850.5
15	Logging, sawmills	29,485.4	36,735.6	1,403.1	42,580.1	4,095.7	50,564.4	3,901.9
16	Other lumb., wood prod.	7,296.6	8,833.8	2,826.2	10,094.9	10,537.1	11,868.8	10,331.9
17	Paper, allied prod.	169,914.6	221,674.0	325.9	269,968.6	1,190.2	339,483.2	1,505.2
21	Petroleum refin.	11;276.0	12,414.9	100.6	13,370.5	310.4	14,777.4	452.6
29	Machinery, exc. elect.	9,247.4	9,247.4	—	9,971.6	391.0	13,126.6	286.4
32	Transport, except:	171,111.6	202,799.4	744.9	233,166.5	2,510.1	274,960.3	2,841.3
33	Rail transport	102,038.0	118,963.0	958.8	131,155.9	2,806.1	147,497.6	3,056.1
35	Truck transport	4,181.1	4,749.4	225.0	5,250.2	838.0	5,968.2	870.9
37	Communication	67,269.0	73,845.2	579.3	77,733.5	2,187.9	83,895.7	3,313.9
38	Electric	133,676.0	149,533.2	10,166.2	171,201.0	11,788.3	202,842.2	12,770.4
41	Wholesale trade	135,570.5	157,180.0	1,639.1	173,352.7	5,426.9	197,628.7	6,971.5
42	Retail trade	149,653.1	169,128.0	975.7	178,682.2	4,718.2	194,436.0	8,418.2
49	Medical, educ. org.	75,658.4	80,459.1	—	80,459.1	—	80,459.1	—
50	Fed. enterprises	5,745.5	6,217.2	88.0	6,567.1	185.6	7,094.5	265.8
53	Other government	—	—	—	—	—	—	—
Column total		1,366,334.5	1,560,478.5	20,590.6	1,742,343.8	51,514.2	1,999,925.1	60,474.7
Total (all 53 sectors)		2,401,176.4	2,712,023.4	22,261.5	3,115,099.8	56,118.2	3,695,819.5	67,485.7
Grand total		2,401,176.4	2,734,284.9		3,171,218.0		3,763,305.2	

[1] See table 6 for complete titles.

age-class distributions be brought into full regulation after nearly one rotation, but allowable cut could be substantially increased over time. This would level off to greater than 550,000 cords/year on aspen cover type alone. Considering the other hardwood types (but still ignoring nonindustrial private ownerships), the magnitude of the potential resource becomes evident.

A composite scenario of industrial development was devised to utilize the large potential increase in hardwood harvests available from state, county, and forest industry lands. Development of four waferboard plants and a wood-fired electrical generation plant between 1980 and 1990 was assumed in the hypothetical expansion. This was the linking element between the output of the biological model, FREP, and the socioeconomic model, REIFS. Input requirements were determined for all facilities in terms of wood and construction costs. Their associated final output, valued approximately as they would be sold in the region, were calculated. Direct effects on other sectors of the economy as a result (e.g., truck transport to haul final waferboard product), were also determined.

The waferboard plants and 25 MW wood-burning electrical plant caused noticeable impacts to the study area economy. Expansion in the construction, wood products, logging, electrical, and truck transport sectors were shown to influence numerous variables, some more than others. Tables 7-11 highlight the more noticeable impacts on total population, employment, gross output, earnings, and capital stock. A predicted decline of 58,383 in regional population from 1977 to year 2000 was lessened to a decline of

49,883. Moreover, significant increases, or perhaps offset of decreases, in preschool and school age children occurred by the end of the projection period. The importance of such figures could weigh heavily in educational planning, especially if school closures and/or reductions in educational staffs loom ahead.

As a result of industrial expansion, employment expanded substantially by the year 1992. Over 1,000 jobs were created in the timber-based sectors alone. By the year 2000, the wholesale-retail trade sectors indicated an increase of 1,381 jobs to offset the predicted decrease in employment for that sector. But the more striking trend was in a sector that showed a predicted employment increase even in the absence of development. Over the period 1977 to 2000, employment in the government services sector increased nearly 4.7 percent in response to development. In relative terms, the wood products sector increased most significantly; but retail trade had a larger absolute increase in jobs in this scenario.

Without development, gross output, based on historical worker productivity, was predicted to increase from 1977 to the year 2000 by better than 53 percent. With development, this increase was boosted to nearly 58 percent. The government sector showed the second largest increase in gross output. Investments in capital stock showed greater increases with development than without. The electrical service sector showed the greatest investment increase, valued at $12.77 million (in 1970 dollars) for the year 2000. The wood products sector was close behind at $10.3 million. Pollution abatement equipment weighed heavily in these increases, especially in the electrical service case.

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APPENDIX

Determination of Waferboard Price, Wholesale, FOB at Mill

This was accomplished by starting with the retail price of the product and working backwards to strip off the cost of doing business margins for retail, wholesale, and transportation. Published by Dun and Bradstreet, Inc. for 185 lines of business,[4] these ratios represent a percentage of business receipts as reported by a representative sample of the total of all Federal income tax returns for 1969-1970. Total business receipts for each sector (i.e., retail, wholesale) equal the cost of goods sold plus the gross margin. It is this gross margin that is stripped off for each sector.

Retail price 8′ x 4′ ($\frac{3}{8}''$) or 1 ft^3 = $\$7.39$ (1979[5])

• less retail gross margin for building materials, hardware, farm equipment (24.35 percent)	− 1.80
	$\$5.59/\text{ft}^3$
• less wholesale gross margin for lumber and construction materials (16.39 percent)	− .92
	$\$4.67/\text{ft}^3$
• less transportation cost (see next section)	− .25
Wholesale, FOB, at mill	$\$4.42/\text{ft}^3$ (1979 $\$$'s)
Deflated by Consumer Price Index to 1970	$\$2.34/\text{ft}^3$

Determination of Transportation Costs for Waferboard

The quoted price currently charged by the State of Minnesota, Department of Transportation, from Grand Rapids to St. Paul-Minneapolis is 63¢ per 100 weight (40,000 lb minimum). Transport cost per ft^3 follows from:

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[4] *Dun & Bradstreet, Inc. 1973. Cost of doing business: corporations. Key business ratios for 1969-1970. New York, New York.*

[5] *Knox Lumber Co., St. Paul, Minnesota, as of November 1979.*

$$\frac{\$0.63}{100\ \text{lb}} \times \frac{40\ \text{lb}}{\text{ft}^3}\ \text{(approximate waferboard density)}$$
$$= \$0.25/\text{ft}^3.$$

Because this value is based on the Grand Rapids-Twin Cities highway distance, it was changed to a per-mile rate and expanded to estimate the rate to Virginia, Minnesota. This hypothetical regional center resulted in a 70¢/100 weight rate, or 28¢ per ft³ in 1979 terms. During the first year of a waferboard plant's operation, the transportation sector would haul one-half the amount it would the following year:

Full production 150 mm ft² (3/8″) = 4,687,500 ft³,
4,687,500 ft³ x \$0.28/ft³ = \$1,312,500 (1979),
\$1,312,500 deflated by CPI = \$695,733 (1970) in full production for transportation sector,
First year of waferboard plant operation = \$348,000 (1970) for transportation sector.

Determination of Cord-input Requirements (volume)

Based on the 1,235 kg dry wood input per 1 ton output conversion factor for flakeboard (Vajda 1975), the cord-aspen per mm ft² (3/8-inch thick basis) equivalent was determined as follows:

Assuming 83 ft³/cord for aspen,

$$\text{then } \frac{83\ \text{ft}^3}{\text{cord}} \times \frac{26.6\ \text{lbs}}{\text{ft}^3}\ (12\ \text{percent m.c.})$$
$$= \frac{2{,}208\ \text{lbs}}{\text{cord}} \left(\frac{1{,}001\ \text{kg}}{\text{cord}}\right),$$

and 1,235 kg "dry" wood input translates into

$$\frac{1{,}235\ \text{kg}}{1{,}001\ \text{kg/cord}} = 1.2338\ \text{cords input for 1 ton output.}$$

Assuming density of waferboard is approximately $\frac{40\ \text{lbs}}{\text{ft}^3}$, then input of 1.2338 cords for 2,000 lbs output (1 ton) yields

$$2{,}000\ \text{lbs} \times \frac{\text{ft}^3}{40\ \text{lbs}} = 50\ \text{ft}^3\ \text{output.}$$

Now, 1.2338 cords input yields 50 ft³ output,

$$\text{or } \frac{50\ \text{ft}^3}{0.03125\ \text{ft}\ (3/8\ \text{in.})}$$
$$= 1{,}600\ \text{ft}^2\ \text{on 3/8-inch thick basis.}$$

Then 1.2338 cords yields 1,600 ft² (3/8 in.) or 7.71125 x 10^{B4} cords/ft² (3/8-inch thick), equalling approximately 771 cords input/mm ft² (3/8 in.).

Adjustments of Transportation and Logging Sector Inputs

As referred to earlier, the table of technical coefficients (i.e., input-output ratios) in SIMLAB were not fine-tuned adequately for the new industries proposed in the scenario. Consequently, adjustments were made to the values of final demand that were inputs in the SIMLAB development case projection (table 4 in text). The following example shows how this was done.

For the year 1985, the wood products sector final demand (output) was \$10,969,000. This represented one 150 MM ft² (3/8-inch thick) waferboard plant at full production (150 MM ft² x \$73.125/M ft²). The corresponding transportation output was, as shown earlier, \$696,000 (rounded). The technical coefficient to be checked in the input-output table reflected a value of 0.002866. That is, to produce \$1 of output in wood products, \$0.002866 was purchased from sector No. 35, motor freight. But the 1985 final demands indicated:

$$\frac{\$\ \ 696{,}000\ \text{(transport output)}}{\$10{,}969{,}000\ \text{(wood prod. output)}} = \$0.063452$$

The scenario shows that slightly more than \$0.06 is purchased in motor freight for every \$1 of waferboard sold. The model, then, is not accounting for \$0.060586 (\$0.063452–\$0.002866) in transportation per \$1 of wood product. Hence, the transportation final demand is increased to pick up only that portion that the model will not account for:

$$\$0.060586 = \frac{\text{adjusted transportation final demand}}{\$10{,}969{,}000}$$

Adjusted transportation final demand = \$664,568. The value of \$664,568 for year 1985, in the transportation sector, is what is shown in table 4 and is used to modify the SIMLAB development case projection. This was done, similarly, for the logging sector and both were modified each year as necessary. In year 1991, the model adequately accounted for final demand in the logging sector, hence no final demand (output) was added.

Erkkila, Daniel L.; Rose, Dietmar W.; Lundgren, Allen L.
Estimating economic impacts of timber-based industry expansion in northeastern Minnesota. Gen. Tech. Rep. NC-82. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1982. 21 p.

Analysis of current and projected timber supplies in northeastern Minnesota indicates that expanded timber-based industrial activity could be supported. The impacts of a hypothetical industrial development scenario, including construction of waferboard plants and a wood-fueled power plant, were estimated using an input-output model. Development had noticeable impacts on the study area economy, e.g., regional employment and gross output.

KEY WORDS: Input-output model, development scenarios, timber supply, inventory projection.

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General Technical Report **NC-83**

The Mack Lake Fire

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Front Cover Photo.→*The Mack Lake Fire shortly before it passed through the village of Mack Lake. Note the spot fire on the edge of the lake. Photo courtesy of the Huron-Manistee National Forest, Mio Ranger District.*

PREFACE

The full story of a major wildfire contains many chapters, such as organization, suppression, and logistics. This report on fire behavior is only one chapter in the story. In limiting our observations to fire related phenomena, our conclusions must also be limited to fire's contribution to the outcome of events. Thus, the report does not address management concerns involving actions taken or not taken. These have been adequately discussed in a previous report (USDA Forest Service 1980) and will not be repeated here.

The reader may note differences between information presented herein and that previously published. Earlier information was based on preliminary analyses of incomplete data. This report reflects a comprehensive analysis of all available data as well as a thorough review. Thus, where differences exist, this report should be considered correct.

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THE MACK LAKE FIRE

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On May 5, 1980, at 1030 EDT,[1] a prescribed fire was ignited in jack pine slash near Mio, Michigan (fig. 1). The purpose of the burn was to remove logging debris up to 1 inch in diameter in preparation for replanting jack pine. The ultimate objective was to create habitat favored by the endangered Kirtland's warbler. At 1206, the fire spotted into standing jack pine timber adjacent to the prescribed burn area. At 1215, the fire spotted across Michigan Highway 33 and became a wildfire. In the first 3-½ hours, during which the fire advanced 7-½ miles, no amount of fire line or road width held or slowed the fire. After the fire had advanced 4 miles, the passage of a dry cold front turned the southeast flank into a head fire. In the first 6 hours, the fire took one life, destroyed 44 homes and buildings, and burned 20,000 acres of forest land. Aided by a change in fuels and ameliorating burning conditions, suppression crews contained the fire by constructing 35 miles of fire line just 30 hours after it started, at a final size of 24,000 acres. In consuming 270,000 tons of fuel, the fire released 3 trillion Btu's of energy—as much as 90 thunderstorms, or nine times the energy released by the Hiroshima atomic bomb.

Although the Mack Lake Fire is the largest fire recorded on the Huron National Forest since record keeping began in 1911, it is not comparable to the historically "great" firest in the Lake States. Between 1871 and 1918, fires in Michigan, Wisconsin, and Minnesota burned 1 million or more acres in each of six different years and resulted in 2,500 deaths (Plummer 1912, Guthrie 1936). Simard and Blank (1982) found that within the area burned by the Mack Lake Fire, there have probably been five other fires in excess of 10,000 acres since 1820 (one every 28 years including Mack Lake). In 1946, six fires burned 14,300 acres in 1 day under similar weather conditions. Given that fires will continue to occur, and that critical weater conditions will occasionally prevail, there is every reason to expect that some future jack pine fires will escape initial attack. Thus, a case study documentation of the Mack Lake Fire is important not only as a historical account of events but also as a valuable guide for future fire suppression planning.

Trying to understand the behavior of all large fires with individual case studies is like trying to understand a movie by examining individual frames chosen at random. Each fire is only a single observation of a complex process, and many observations are

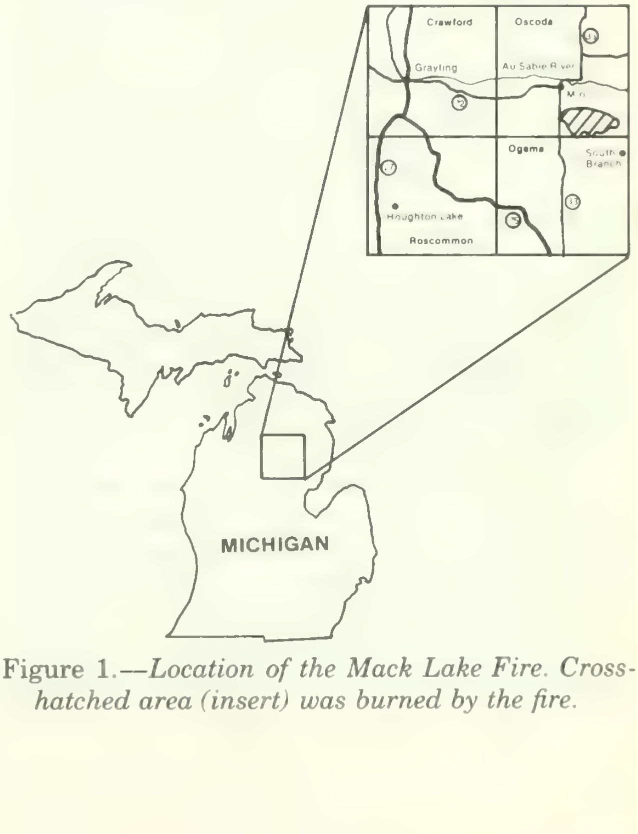

Figure 1.—*Location of the Mack Lake Fire. Cross-hatched area (insert) was burned by the fire.*

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[1] *All times in this paper are Eastern Daylight Savings time, unless otherwise noted.*

needed before patterns begin to emerge. Despite the complexity, however, careful examination of even a single fire can yield insights into the underlying physical processes that control large fire behavior.

METHODS

The authors were assigned to the Mack Lake Fire as a fire behavior analysis team. Because all significant fire activity had stopped 20 hours before we arrived at the fire site (1400 on May 6), the investigation was limited to reconstructing past events. Some important observations could not be obtained (e.g., a light rain precluded meaningful fuel moisture measurement).

Between May 6 and 9, we observed the burned area by aircraft and vehicle. The prescribed fire, escape, and fatality areas were observed in detail. General fuel conditions were assessed and fuel weights sampled to estimate consumption. We took numerous still photographs and examined video tapes and polaroid photographs of the fire along with aerial photos of the burned area. We interviewed members of the burning (and initial attack) crew, the meteorologist-in-charge of the nearby Houghton Lake National Weather Service office, and senior fire management specialists having extensive experience with jack pine crown fires. We examined relevant documents: witness statements (obtained by ourselves and the accident investigation team), local weather records, the Mio Ranger District log, the prescribed burning plan, and documentation of the fire itself.

Although efforts were made to verify all indirect information, portions of this report are based on hearsay evidence. Further, at the time the fire made its major run, personnel were concerned with fire control and not documenting observations. Additionally, the major run occurred while the control organization was reorganizing from initial attack to project fire status (USDA Forest Service 1980). Therefore, few experienced persons observed the fire. Despite these limitations, the authors feel that the following description is a reasonably accurate chronicle of the events that occurred and conditions that preceded the Mack Lake Fire.

During the months that followed the fire, we analyzed additional data. Growth rings from 14 large red pine trees killed by the fire were counted to determine the area's fire history (Simard and Blank 1982). Antecedent meteorological conditions were summarized from district fire weather records and climatological data obtained from the Michigan State Climatologist. We obtained additional fuel loading measurements from burned and adjacent unbur areas. Seed fall and seedling counts were take estimate regeneration success. A rain gauge netw was installed to monitor postburn precipitation nally, we examined unburned tree crown strip detail to determine possible underlying causes.

THE ENVIRONMENT

Weather

Fire Climate

As a result of the Great Lakes' influence, Lo Michigan has a semimarine climate. The lake ir ence is lessened at Mio, which is sheltered from L Michigan by a higher plateau to the west. Mio a 1°F higher average maximum temperature, a cooler average minimum temperature, and an erage of 6 inches less annual precipitation than tions 30 to 40 miles to the northwest. The hig temperature in Michigan (112°F) was recorded Mio on July 13, 1936 (Michigan Weather Ser 1974).

Although the average 26.5 inches of precipita is well distributed throughout the year, twice as m falls in the summer (3 inches per month) as in winter (1.4 inches per month), with spring and in between (2.25 inches per month). Average mon relative humidity at 1300 is lowest in May (50 cent) and average monthly windspeed peaks at mi/h in April. Evaporation during the growing son exceeds precipitation by 45 percent. Altho periodic mild droughts occur, extreme severity on Palmer scale is experienced only 3 percent of the t (Michigan Weather Service 1974).

The most severe fire weather in Michigan mally occurs when the Lake States are on the no west or back edge of a Hudson Bay, northwest nadian, or Pacific high pressure area (Schroeder Buck 1970). Generally, air masses and associa frontal systems move through the region in a so easterly direction every 3 to 5 days. When a h pressure system persists longer than normal, h ever, fuels have more time to dry out. The appro of a cold front aggravates the situation by increa the flow of dry, warm air from the southwest. sequently, peak fire danger is expected when the I States have been under extended high pressure fluence just before the passage of a cold front happened, for example, prior to the Peshtigo Great Chicago fires of 1871 (Haines and Kueh 1970). Precipitation associated with frontal pas normally ends the period of high fire danger.

'he Fire Season

Total precipitation for 1979 recorded at Mio was 7.6 inches—1.2 inches (4 percent) above normal. recipitation was well distributed throughout the ear, with only 2 months (February and September) eceiving less than 1.5 inches. Total precipitation om January through April was 5.4 inches—1 inch .6 percent) below normal. The Palmer Drought In-ex at the time of the fire was −1.17, indicating a ight, but insignificant, soil moisture deficit. We may, ierefore, conclude that drought was not an impor-nt factor in the Mack Lake Fire.

Winter snowfall was 45.5 inches—15.9 inches (26 ercent) below normal. The shortfall was not uni-rmly distributed throughout the winter. Between ctober and February, the snowfall was only 49 per-nt of normal. Because (1) the maximum snow depth as only 11 inches, (2) there were only 14 days with or more inches of snow on the ground, and (3) the aximum single snowfall was only 4 inches, there as minimal fuel bed compaction. Field personnel ported that dead grasses and herbaceous material ere standing at the time of the fire rather than ing flat, as is usually the case.

Daily 1300 weather observations and fire-danger tings for April and the first few days of May at io are listed in table 1. Based on the National Fire-anger Rating System (NFDRS) Burning Index (BI) eeming *et al.* 1977), fire danger during the season as either high to extreme (19 days, 53 percent) or w (15 days, 42 percent), with little in between (2 ys, 5 percent) (fig. 2). On six occasions, the index mped from low to high (or vice versa) in a single y. The BI indicates three fire danger peaks in the ry high range and one in extreme, with the May peak the third highest during the season.

ynoptic Pattern

The Hudson Bay high pressure area that was to fluence Michigan on May 5 first formed over south-n Alberta on April 22. On April 29, a cold front on e southeast edge of the high pressure area passed er Michigan, dropping ½ inch of rain at Mio.

By May 1, Michigan was under the influence of e high, which was centered over northern Min-esota. The cold front that was to pass over the Mack ake Fire appeared off the British Columbia coast. y May 2, the high over Minnesota joined with a cond high to the west, placing most of central North merica under its influence. Dry air dropped the 00 relative humidity at Mio to 28 percent and creased the temperature to 75°F. The cold front tended from a low pressure area centered over northern Alberta southward to Los Angeles. It is significant to note that the synoptic pattern over east-central Alberta on May 2 was the same pattern that would move to Michigan on May 5. On May 2, a forest fire in east-central Alberta burned 20,000 acres in the first 5 hours after ignition (Alexander *et al.* 1983).

Table 1.—*1300 fire weather observations and National Fire-Danger Rating System (NFDRS) Burning Index values for Mio, Michigan, for April and May 1980*

Date	Temp.	Relative humidity	Precip.	Windspeed	NFDRS Burning Index
	°F	Percent	Inches	mi/h	Model Q
April 1	57	43		7	62
2	58	21		10	70
3	43	33		16	54
4	52	82	0.43	13	0
5	55	58		15	44
6	51	71		10	47
7	55	60	.01	4	37
8	53	88	.33	4	0
9	48	80	.52	6	0
10	38	83	.31	7	0
11	42	62	.02	4	10
12	37	91	.31	4	0
13	37	66		7	31
14	34	81		9	0
15	38	91	.53	6	0
16	37	33	.03	10	52
17	48	73		8	40
18	63	30		8	58
19	69	33		15	80
20	65	21	.19	5	46
21	69	19		4	49
22	78	34		5	54
23	49	32		15	90
24	40	68	.03	17	73
25	57	37		7	58
26	48	86	.01	7	0
27	49	87	.01	9	0
28	47	93		10	0
29	50	93	.51	4	0
30	56	82		0	0
May 1	65	57		2	10
2	75	28		2	32
3	78	22		7	53
4	80	19		10	63
5	80	24		18	79
6	57	52	.03	2	2

On May 3, the center of the continent was still under the influence of the high. The low moved eastward to northern Saskatchewan and the cold front trailed southwestward to Nevada. On May 4, a flat upper-air pattern persisted over much of the western and north central United States (fig. 3), allowing the

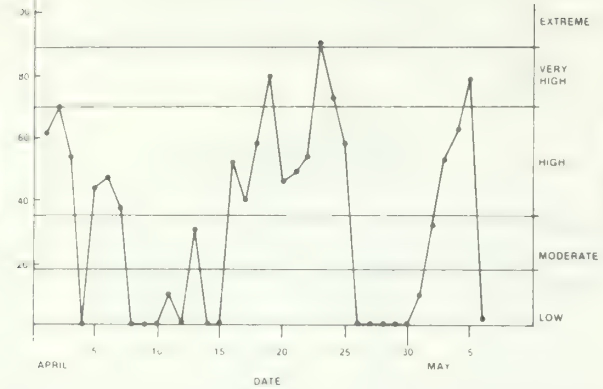

Figure 2.—*National Fire-Danger Rating System Burning Index (fuel model Q) for Mio, Michigan, April and early May 1980.*

Central States to remain under the influence of the weak surface high. It also allowed the slow eastward movement of the cold front, now over the Dakotas. The 1300 relative humidity over Mio dropped to its lowest point (19 percent), temperature rose to 80°F (14° above the average high for May), and winds increased to 10 mi/h.

On the morning of the fire, the 500-millibar chart indicated a high pressure ridge lying over the northern Rockies (fig. 4). A closed low covered eastern Canada with split centers over Newfoundland and Hudson Bay. This produced tightened gradients over the northeastern United States with a northwest flow over the Great Lakes region. The upper air steering caused the surface low pressure area to move southeastward to southern Ontario. Ahead of the weak cold front, relative humidity was low (24 percent) and temperature was unseasonably high (80°F). Windspeed at Mio increased significantly to 15 mi/h, gusting to 25-plus as the front approached. It was during this time that the Mack Lake Fire made its major run. Although the temperature decreased and the humidity increased as the front passed, there was no precipitation. Thus, as the wind direction shifted, the fire continued to burn vigorously and what had been the southeastern flank became a wide front.

By May 6, the 500-millibar chart showed that the Hudson Bay low-pressure center was north of Lake Superior (fig. 5). A shallow trough originating from it lay over Lower Michigan, producing cloudy skies and occasional light showers (0.03 inches). A weak pressure gradient behind the cold front (now over southern Ohio) resulted in light afternoon winds (2 mi/h) which, along with increased humidity (52 percent), moderated burning conditions, allowing the fire to be easily controlled.

The Day of the Fire

Hourly relative humidity and temperature rea
ings were obtained from a hygrothermograph[2]
cated at Mio (table 2). Hourly windspeed and wi
direction for Houghton Lake (35 miles away) on M
5 are also given in table 2. By 1000, the temperatu
had reached 75°F and relative humidity had dropp
below 30 percent, where they remained for the ne
5 hours. The maximum temperature (83°F) was 17
higher than the average maximum for May at M
(Michigan Weather Service 1974). Minimum relati
humidity (21 percent) was well below the May a
erage (51 percent) for Houghton Lake. Climatolo
ical data indicate that in the Lake States, relati
humidity is lower than 25 percent on fewer than
percent of all days.

Between 1000 and 1900, the front moved at
average of 23 mi/h (Falkowski 1981). Until 14
winds were southwesterly, varying from 5 to 12
h. By 1400, the leading edge of the front passed (f
6) and windspeed increased to 15 to 18 mi/h wi
gusts of 25 to 30 mi/h. Although the wind directi
shifted 40° to west-northwest, there was no app
ciable change in either temperature or humidity.
1700, the wind shifted another 40° to north-nort
west, accompanied by a slight temperature decrea
and humidity increase. The peak gust for the d
(30 mi/h from the northwest) occurred at 1728 E
After the front passed, the temperature and wi
gradually decreased and humidity increased.
though the fire continued to burn during the nig
its forward rate of spread gradually decreased to
by morning.

Schroeder and Buck (1970) state that "Atm
pheric stability may either encourage or suppre
vertical air motion." The strength of the convecti
activity above a fire will affect the indraft at t
surface and consequent fire intensity. The indr
may also reduce the rate of spread of a fire with
well-developed convection column. Brotak (19
measured the atmospheric stability associated wi
62 major wildfires in the eastern United States.
employed a simple indicator of stability by calcul
ing the temperature difference between the 950- a
850-millibar pressure levels. Most of the fires studi
(92 percent) occurred when the lapse rate betwe
these levels was steeper than the dry adiabatic la
rate (5.5°F per 1,000 feet). He concluded that a te
perature difference of at least 11°F between the 9
and 850-millibar levels appears to be associated wi
major fires.

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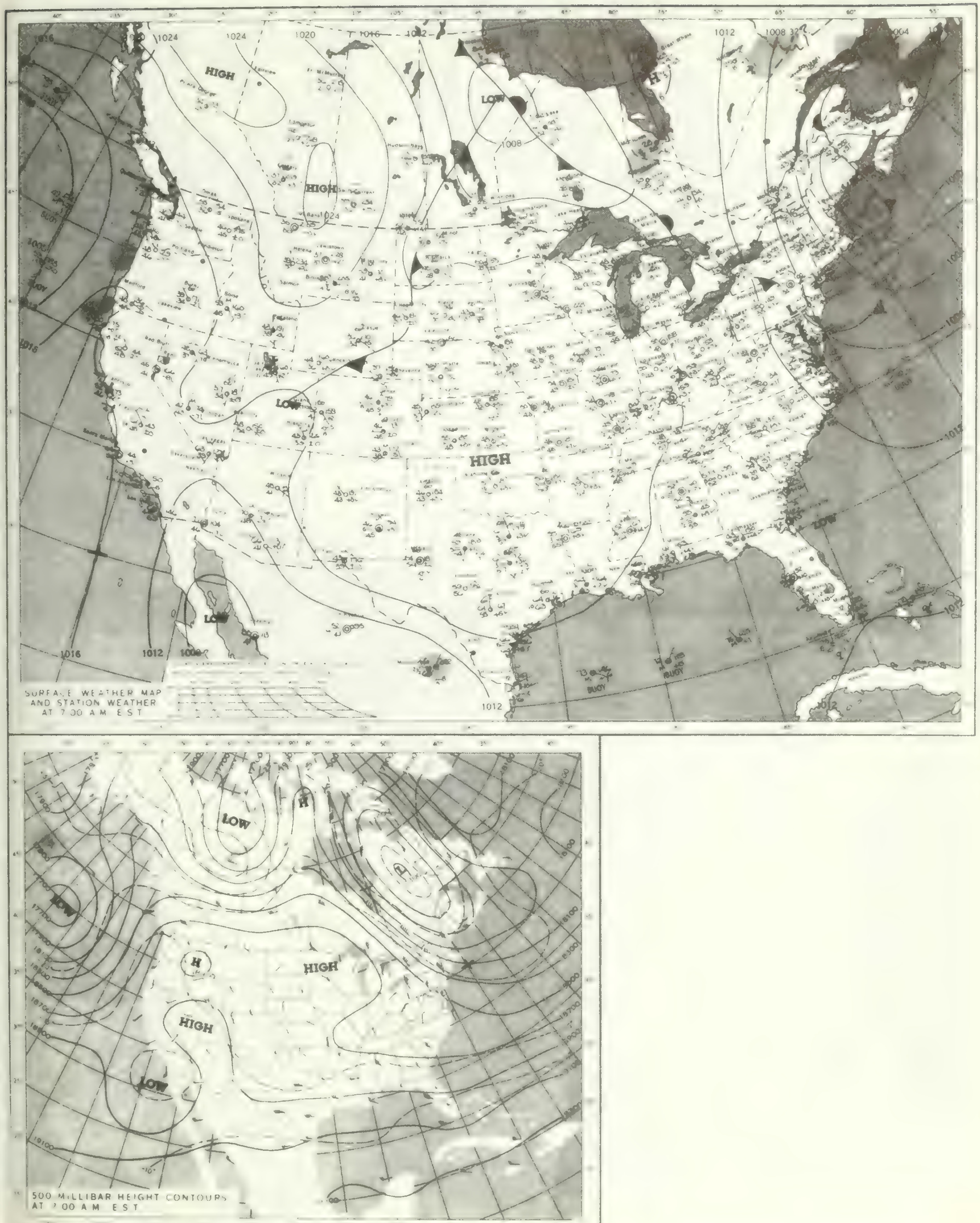
[2] *Hygrothermograph readings normally dif
slightly from psychrometer readings used to meas
weather inputs to the NFDRS (table 1).*


SURFACE WEATHER MAP AND STATION WEATHER AT 7:00 A.M. E.S.T.
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500 MILLIBAR HEIGHT CONTOURS AT 7:00 A.M. E.S.T.
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Figure 3.—*Surface weather map and 500-millibar chart for May 4, 1980 (from U.S. Department of Commerce 1980).*

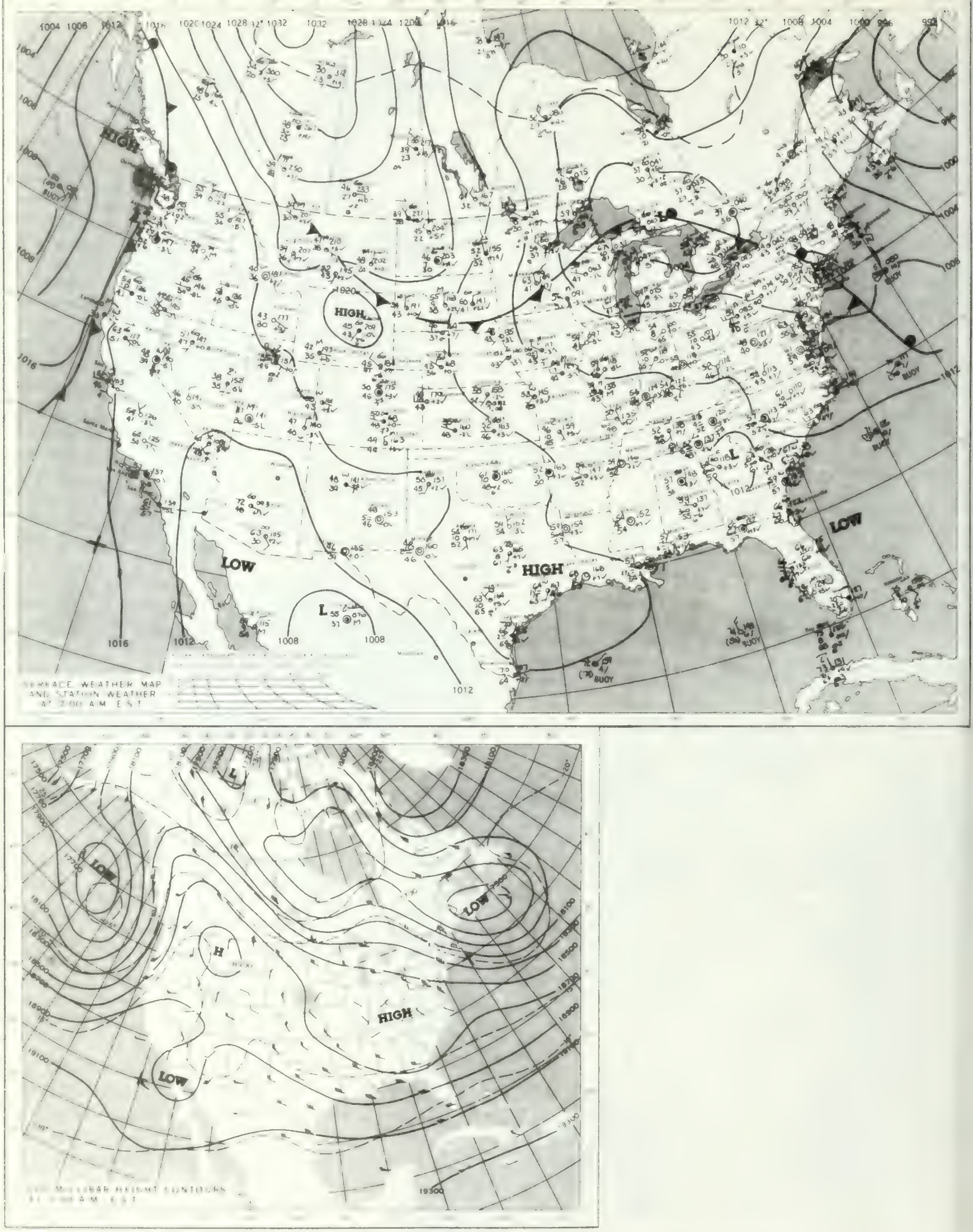
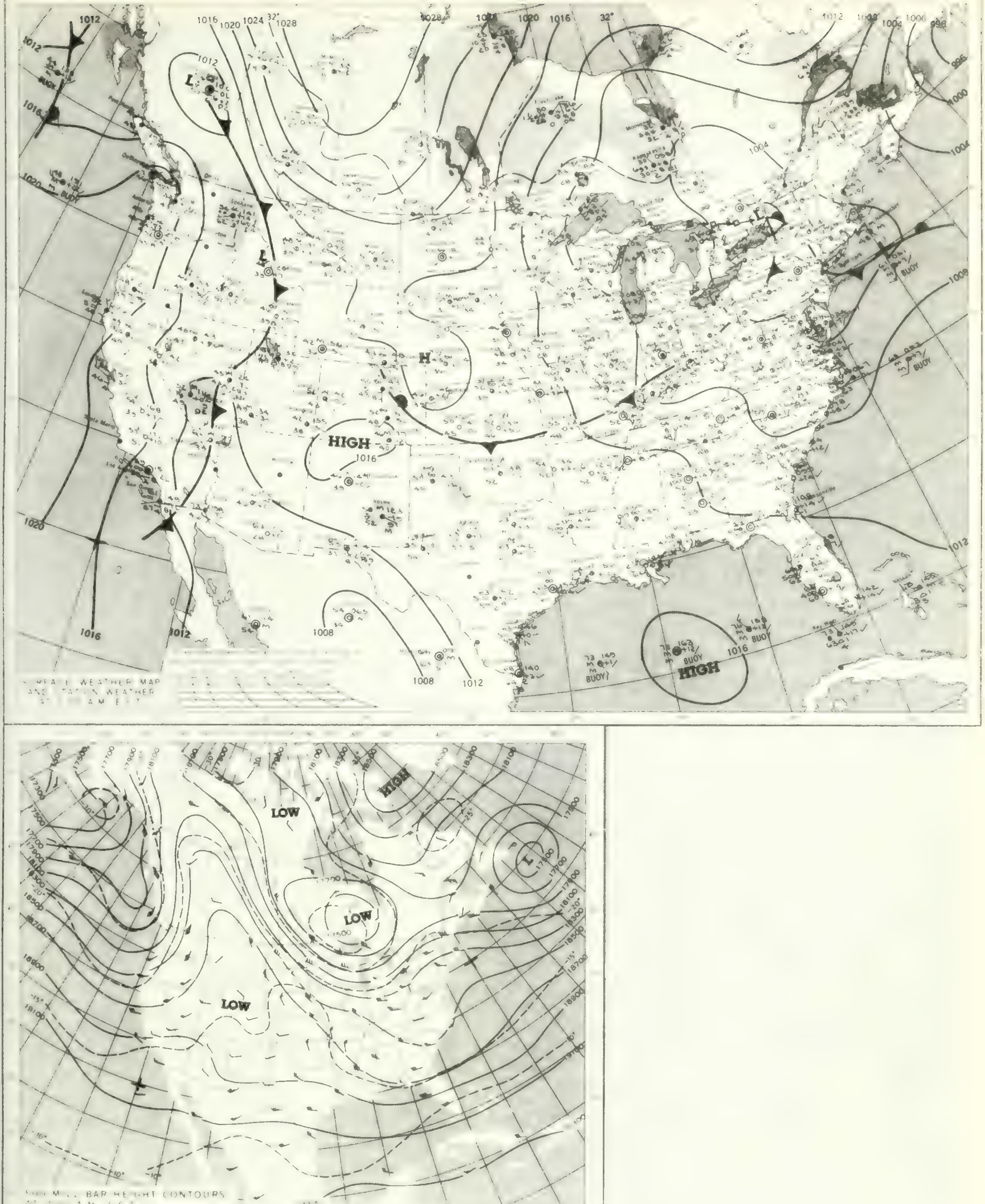


Figure 4.—*Surface weather map and 500-millibar chart for May 5, 1980 (from U.S. Department of Commerce 1980).*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SURFACE WEATHER MAP AND STATION WEATHER AT 7:00 AM E.S.T.
500 MILLIBAR HEIGHT CONTOURS AT 7:00 AM E.S.T.

Figure 5.—*Surface weather map and 500-millibar chart for May 6, 1980 (from U.S. Department of Commerce 1980).*

Table 2.—*Hourly weather data for Mio and Houghton Lake,[1] Michigan, May 5, 1980*

Time (EDT)	Relative[2] humidity	Temp.[2]	Windspeed	Wind gusts	Wind direction
	Percent	°F	mi/h	mi/h	Degrees
0800	—	57	5	[3]—	230
0900	80	65	8	—	230
1000	28	75	7	—	270
1100	23	80	12	—	230
1200	21	82	8	—	250
1300	22	83	10	—	250
1400	22	82	15	25	290
1500	26	81	18	28	280
1600	37	77	15	25	290
1700	46	71	17	30	330
1800	55	65	17	28	330
1900	56	60	16	24	330
2000	50	57	13	23	320
2100	51	53	12	23	330
2200	54	52	10	—	330
2300	56	50	10	—	330
2400	60	48	8	—	330

[1] Relative humidity and temperature data are from Mio and wind data are from Houghton Lake—a first-order National Weather Service station located 35 miles southwest of the fire.

[2] Hygrothermograph readings which differ slightly from standard 1300 psychrometer data (table 1).

[3] No data available.

The May 5 morning and evening upper air temperature profiles for Flint, Michigan[3] are similar except for a strong morning surface inversion. Therefore, only the evening observation is presented (fig. 7). The sounding shows a conditionally unstable lapse rate from the surface upward, except for a shallow layer (568 to 588 millibars) that approaches isothermal. The air temperature difference between the 950- and 850-millibar levels exceeded 14°F—3°F above the threshold noted by Brotak (1976). Dewpoint values were low, indicating relatively small amounts of moisture throughout the lower atmosphere. The profile suggests that only small amounts of energy were necessary to overcome existing static stability. Consequently, atmospheric conditions favored convective activity, given the initial energy produced by the fire.

Brotak (1976) also found that low-level jet streams were associated with one out of three major wildfires in the eastern United States. The primary mechanism is thought to be downward transport of momentum by turbulent mixing which increases surface windspeed and gustiness. It is reasonable to hypothesize that low-level jets aggravate an already bad situation resulting from the close proximity of a dry cold front.

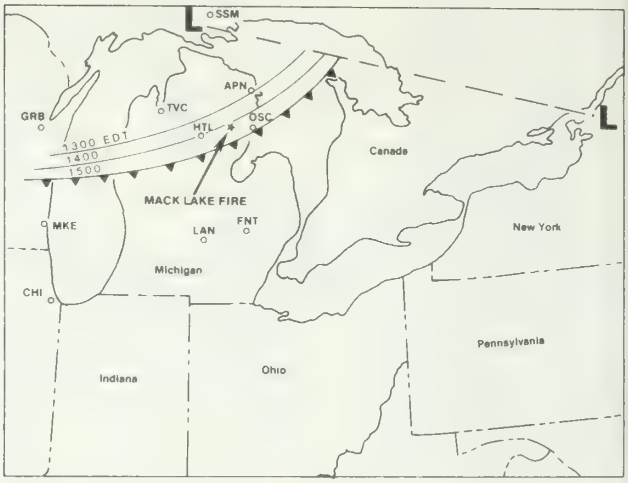

Figure 6.—*Location of the leading edge of the cold front during the afternoon of May 5, 1980.*

Upper level wind information was available from Sault Ste. Marie and Flint, Michigan and Green Bay, Wisconsin. The profiles at 0800 on May 5 show a marked increase in windspeed from the surface to 2,000 feet at Green Bay and Flint, two stations ahead of the cold front (fig. 8). They also show maximum speeds averaging 32 mi/h at 2,000 to 3,000 feet, a decrease to an average of 26 mi/h at 4,000 feet, and little change above 4,000 feet. This is a classic low-level jet profile. The wind profile behind the front

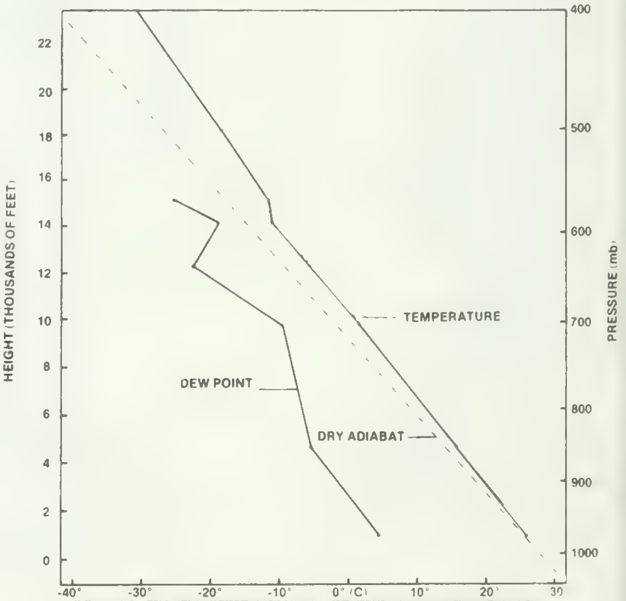

Figure 7.—*Upper air temperature profiles at Flint, Michigan, at 2000 EDT on May 5, 1980.*

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[3] *The closest station to the fire (120 miles away) that reflects air mass conditions over Mio at the time the fire broke out.*

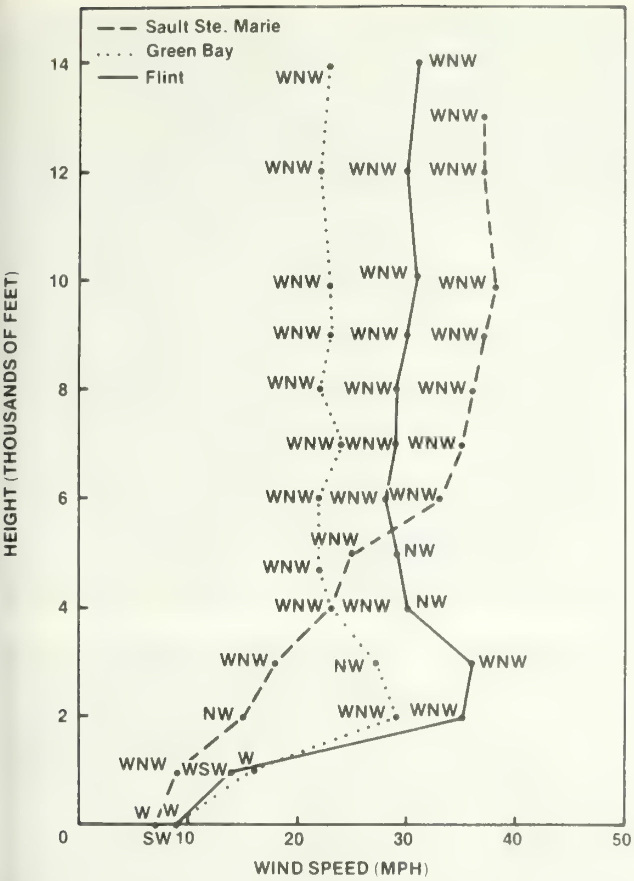

Figure 8.—*Vertical windspeed profiles at Sault Ste. Marie, Michigan; Green Bay, Wisconsin; and Flint, Michigan, at 0800 EDT on May 5, 1980.*

(Sault Ste. Marie) shows generally increasing windspeed with increasing height. This is characteristic of a well-mixed atmosphere which, when coupled with surface cooling after sunset, reduces turbulent mixing and resultant surface winds.

Fuels

General Description

Forty-two percent (10,100 acres) of the total area burned by the Mack Lake Fire had a jack pine (*Pinus banksiana*) overstory (table 3, fig. 9) growing on Grayling sand, which dries rapidly after rain. Part of the area had burned in 1946 and some portions had seeded naturally, while some areas had been planted. The overstory contained mixtures of open areas, reproduction-, sapling-, and pole-sized stands. Much of the latter originated following 1910 to 1913 fires. Part of the area had been prescribed burned in 1964 with subsequent regeneration 5 to 10 feet tall at the time of the Mack Lake Fire. Sixty-two percent of the jack pine was in the pole-size class and 38 percent was in the seedling and sapling class. Overall stand densities ranged from less than 100 stems/acre in open stands to patches of reproduction at densities in excess of 5,000 stems/acre. Pole timber densities generally ranged from 400 to 1,200 stems/acre. Tree heights varied from 20 to 30 feet (4- to 6-inch d.b.h.) to 40 to 60 feet (8- to 10-inch d.b.h.).

Table 3.—*Area burned and fuel consumed on the Mack Lake fire by timber type*

Timber type	Area burned	Percent of total	Fuel consumption
	Acres		*Tons/acre*
Jack pine	10,117	42	9.1[1]
Red pine	3,707	16	10.6[1]
Oak/pine	1,985	8	12.5[2]
Oak/hardwood	2,864	12	14.6
Aspen	3,250	14	14.5
Miscellaneous	320	1	11.2[3]
Private	1,591	7	11.2[3]
Total	23,834	100	11.2[3]

[1] Data from tables 4a and 5a, adjusted downward for 80 percent foliage consumption.

[2] Based on inventory data indicating 50 percent oak, 45 percent red pine, and 5 percent jack pine.

[3] Weighted average of measured fuel types.

Scattered throughout the jack pine area were red pine (*Pinus resinosa*) plantations (3,700 acres) and pine/oak mixtures (2,000 acres). The latter included

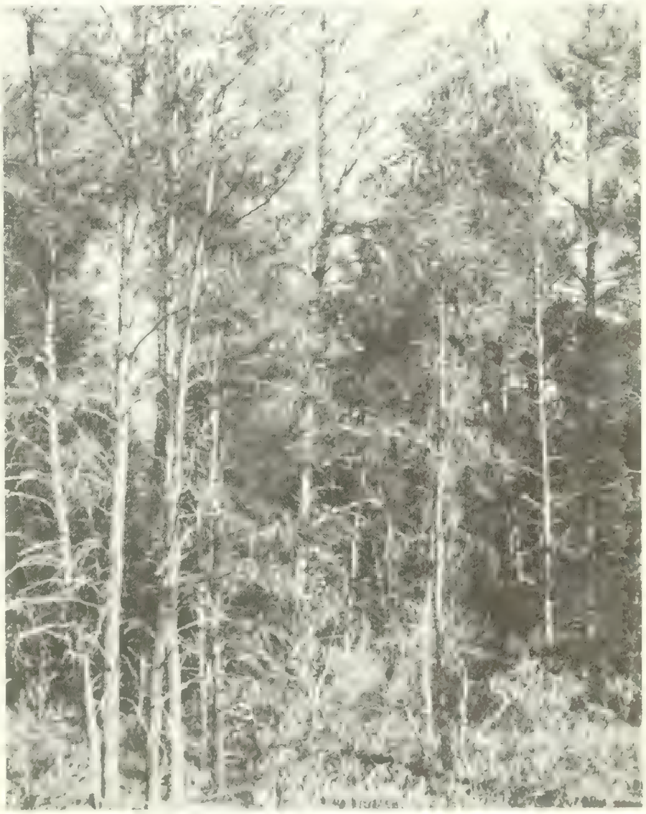

Figure 9.—*Typical jack pine stand.*

northern pin oak (*Quercus ellipsoidalis*), black oak (*Quercus velutina)*, and northern red oak (*Quercus rubra)*. Understory vegetation consisted of sedge (*Carex* spp.), herbs (bracken fern—*Pteridium aquilinum*—fig. 10 (top), trailing arbutus—*Epigaea repens)*, low shrubs (blueberry—*Vaccinium* spp., sweetfern—*Comptonia peregrina*—fig. 10 (bottom)), and moss and lichens (*Dicranum* spp., *Cladonia* spp.). By May 5, the sedges had begun to sprout, the trailing arbutus was in bloom, and the jack pine buds were swelling, but most fuels remained cured.

Along the eastern and southeastern boundaries and in occasional stands throughout the fire area, the fire burned through approximately 6,100 acres of predominantly hardwood stands growing on better soils (e.g., Rubicon). Principal species were northern red, black, and northern pin oak, quaking aspen (*Populus tremuloides)*, paper birch (*Betula papyrifera)*, red maple (*Acer rubrum)*, sugar maple (*Acer saccharum)*, and scattered red pine and white pine (*Pinus strobus)*. Hardwood stands ranged from sapling to mature with generally full stocking. Although the aspen had begun to leaf out and the maple buds were swelling, the hardwood canopy was essentially undeveloped. Throughout the fire area an additional 300 acres of miscellaneous fuels were burned as well as 1,600 acres of unclassified private land.

Fuel Loading

We measured five paired fuel loading plots in burned and unburned areas in pole-sized jack pine stands (fig. 11). Although plots along the edge of the fire may not fully represent fuels and fuel consumption farther inside the burned area, they provide a rough estimate of what took place in the fire. Average loading in the unburned plots for litter, duff, and small twigs was 16 tons/acre and average fuel bed depth was 1.6 inches. These measurements do not differ significantly from those of Walker and Stocks (1975) under immature jack pine stands in Ontario (loading = 19 tons/acre, depth = 1.8 inches). The combined litter and duff bulk density for the Mack Lake area (5.4 lbs/ft^3) was similar to the 5.7 lbs/ft^3 measured by Walker and Stocks (1975) and Brown (1966).

Prefire foliage weights were estimated using Brown's (1965) equation based on data from the Huron-Manistee National Forest. Inputs were: 5-inch d.b.h., 800 stems/acre, and 21 percent of total living crown in foliage. These values yield an estimated foliage weight of 2.2 tons/acre. Using an average 25-foot tree height and an average 5-foot height to base of live crown, the average bulk density of the foliage was approximately 0.005 lbs/ft^3.

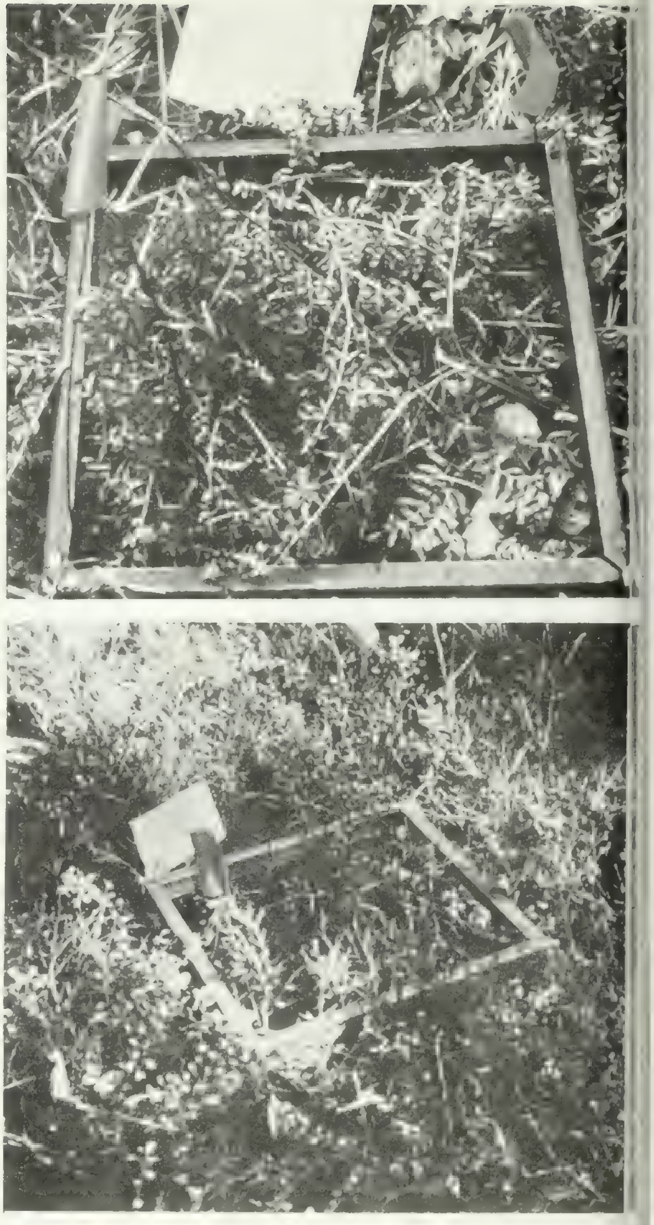

Figure 10.—*Typical bracken fern fuels (top) and typical low shrub fuels (blueberry, sweet-fern) (bottom).*

On the average, 19 tons of jack pine fuel per acre were present before the fire (excluding branchwood) and 9.5 tons/acre remained after the fire for a net consumption of 9.5 tons/acre including crown foliage (table 4a). Estimating that an average of 20 percent of the foliage was not consumed, the average fuel consumption in jack pine was 9.1 tons/acre. Complete fuel consumption was limited to the smallest size classes (litter, small twigs, and foliage). Even here, however, there were striking exceptions, such as an area of reproduction that the fire burned without consuming the foliage. In contrast, only about one-third of the duff and larger woody material was consumed by the fire.

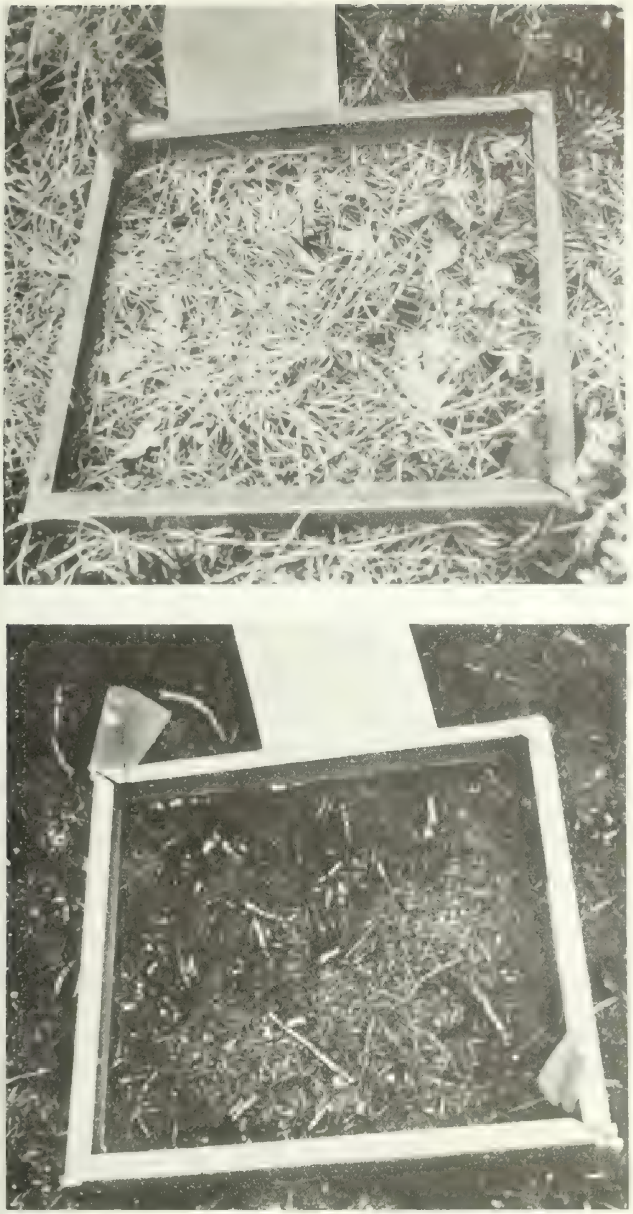

Figure 11.—*Typical jack pine surface litter before the fire (top) and after the fire (bottom).*

Table 4a.—*Average fuel loading and consumption for jack pine stands (5-inch d.b.h., 800 trees/acre, 109 ft^2/acre basal area)*

	Before	After	Consumed
	Tons/acre		
Shrubs, herbaceous	0.6	0.1	0.5
Litter	1.9	.0	1.9
Duff	9.7	6.1	3.6
Wood[1]	4.6	3.3	1.3
Foliage[2]	2.2	.0	2.2
Total	19.0	9.5	9.5

[1] Average for all species (12 samples).
[2] Based on Brown's (1965) equation (not including branchwood).

Table 4b.—*Range of fuel loadings and consumption for jack pine stands (4- to 6-inch d.b.h., 400 to 1,200 trees/acre)*

	Before	After	Consumed
	Tons/acre		
Shrubs, herbaceous	0.0– 2.4	0.0– 0.2	0.0– 2.1
Litter	.2– 5.3	.0	.2– 5.3
Duff	4.2–18.0	1.4–11.7	.8– 7.8
Wood[1]	4.4– 5.0	[4]1.6– 5.3	.0– 2.8
Foliage[2]	1.0– 3.8	.0– 3.8	.0– 3.8
Measured range[3]	11.0–27.2	4.5–16.6	.0–19.1

[1] Average for all species (12 samples).
[2] Based on Brown's (1965) equation (not including branchwood).
[3] Range of individual plots—not the range columns.
[4] The highest woody fuel loading was measured on a burned plot.

Fuel loadings for pole-sized jack pine ranged from 11 to 27 tons/acre before the fire and 4 to 17 tons/acre afterward (table 4b). The total range of jack pine fuel loading varied from 3.5 tons/acre in an open area to more than 50 tons/acre in a fully stocked pole timber stand with precommercial thinning residue underneath. In the latter case, neither the foliage nor the larger surface fuels were consumed (fig. 12).

The prescribed fire area had been whole-tree logged with the slash returned to the cutting area and scattered. The difficulty of achieving a uniform slash distribution resulted in numerous piles of slash throughout the area. Using Brown's (1965) equation for predicting logging residue from stand characteristics, we estimate that 20 tons/acre were left after

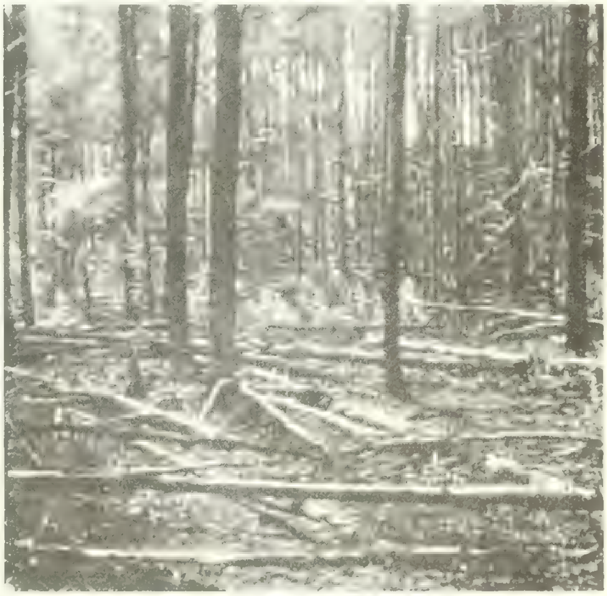

Figure 12.—*Mature jack pine stand with unconsumed precommercial thinning residue underneath.*

cutting in the prescribed burn area. From table 4a, an additional 12 tons/acre of litter, duff, and herbaceous material were present, of which 6 tons/acre were consumed. Therefore, the total prefire loading on the prescribed burn site was 32 tons/acre and total consumption was 26 tons/acre.

Total prefire loading for red pine (21 tons/acre) was similar to that for jack pine (table 5a). There was more litter, less duff, and more estimated foliage in the red pine stand. Combined bulk density for red pine litter and duff (2.8 lbs/ft^3), however, was half that for jack pine. Based on three paired plots, total consumption for red pine was 12 tons/acre. Adjusting downward for 80 percent foliage consumption yields an average consumption of 10.6 tons/acre in red pine.

Prefire surface fuel loadings for aspen (22.5 tons/acre) and oak (40 tons/acre) were greater than that for the pines (tables 5b, 5c). The major difference was in the litter and duff layers. Aspen stands contained 60 percent more material (by weight) than the pine stands, and oak stands were three times heavier. Average depth of litter and duff in the aspen stands was 1.9 inches, yielding a bulk density of 5.1 lbs/ft^3. Litter and duff under the oak stand averaged 2.6 inches deep, yielding a bulk density of 7.4 lbs/ft^3. Based on six paired plots, fuel consumption in the aspen and oak stands averaged 14.5 tons/acre.

Table 5a.—*Average fuel loading and consumption for red pine stands (8.0-inch d.b.h., 143 ft²/acre basal area)*

	Before	After	Consumed
	Tons/acre		
Shrubs, herbaceous	0.2	0.0	0.2
Litter	5.3	2.7	2.6
Duff	4.7	3.0	1.7
Wood[1]	4.6	3.3	1.3
Foliage[2]	6.0	.0	6.0
Total	20.8	9.0	11.8

[1] Average for all species (12 samples).
[2] Based on Brown's (1965) equation (not including branchwood).

Table 5b.—*Average fuel loading and consumption for quaking aspen (7.3-inch d.b.h., 80 ft²/acre basal area)*

	Before	After	Consumed
	Tons/acre		
Shrubs, herbaceous	0.3	0.0	0.3
Litter	3.9	1.0	2.9
Duff	13.7	3.7	10.0
Wood[1]	4.6	3.3	1.3
Total	22.5	8.0	14.5

[1] Average for all species (12 samples).

Fuel loading in a typical sedge area was 3.5 tons/acre, of which 2.6 tons/acre were consumed (table 5d). This was the lowest fuel loading found on the fire site. There is no estimate available of how much of the total area burned was in this fuel type.

Fuel consumption by timber type is summarized in table 3. A weighted average of 11.2 tons/acre of fuel was consumed. Multiplying by the total area burned yields an estimated 267,000 tons of fuel consumed by the Mack Lake Fire.

Fuel Moisture

Surface fuels.—Fuel moisture data were not available for the day of the fire. Two fuel moisture stick observations at 1300 EDT were available from Mio—USDA Forest Service (11 percent) and Michigan Department of Natural Resources (8 percent). Using Simard's (1968) equation and the 1400 observations at Mio (table 2), equilibrium moisture content was determined to be 5 percent. The National Fire-Danger Rating System 1-hour time lag fuel moisture prediction was 6 percent, and the Canadian Fire Weather Index fine fuel moisture code estimate was 7 percent. It is reasonable to assume, therefore, that the primary cured fuels involved in the fire had moisture contents between 5 and 10 percent.

Fuel moisture samples were taken on May 6, 2 hours after a trace of rain had fallen. Lichen and

Table 5c.—*Average fuel loading and consumption for black oak stands (7.5-inch d.b.h., 95 ft²/acre basal area)*

	Before	After	Consumed
	Tons/acre		
Shrubs, herbaceous	0.2	0.0	0.2
Litter	8.9	3.5	5.4
Duff	26.6	18.9	7.7
Wood[1]	4.6	3.3	1.3
Total	40.3	25.7	14.6

[1] Average for all species (12 samples).

Table 5d.—*Average fuel loading and consumption for sedge areas*

	Before	After	Consumed
	Tons/acre		
Shrubs, herbaceous	0.5	0.2	0.3
Litter	.1	.0	.1
Duff	2.3	.7	1.6
Wood	.6	.0	.6
Total	3.5	.9	2.6

bracken fern had moisture contents of 20 and 19 percent, respectively. Clearly they would have been lower on May 5. Blueberry stems had a 67-percent moisture content. Although this is lower than reported minimum values (105 percent) during the growing season in Michigan (Loomis and Blank 1981), our sample included only woody stems, whereas previous data included foliage as well as stems.

Foliage moisture.—Van Wagner (1967) found a spring dip in jack pine foliar moisture starting 4 to 6 weeks prior to flushing (fig. 13). Average jack pine twig and foliage moisture content measured 2 to 5 days after the Mack Lake Fire was 120 percent, with a range of 100 to 135 percent (10 samples). Although this is higher than the minimum noted by Van Wagner (100 percent), it is lower than the average moisture content throughout the rest of the year.

Stashko and McQueen (1974) state that 1 or 2 days of high wind and low relative humidity can reduce foliar moisture content by as much as 20 percent. Data from Grieve and Such (1977) indicate short-term jack pine foliar moisture content variations on the order of 10 to 40 percent, which they attribute to sampling error. It is possible, however, that on porous soils such as Grayling sand, foliar moisture stress can be induced on dry, windy days. Therefore, it is possible that on the day of the fire, foliar moisture could have been 10 to 15 percent lower than our measurements indicate.

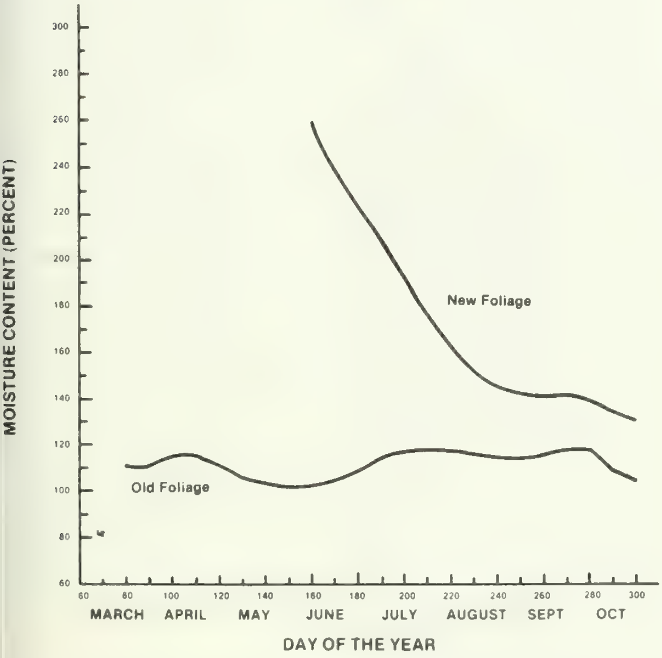

Figure 13.—*Annual trend in jack pine foliar moisture at Petawawa, Ontario (from Van Wagner 1967).*

Van Wagner (1974a) states that the difference between spring and summer foliar moisture can double the rate of crown fire spread. Grieve and Such (1977) indicate that jack pine crown fires are likely at moisture contents below 135 percent. They note, however, that high jack pine foliar moisture coincides with green surface vegetation, and low foliar moisture coincides with cured surface vegetation. They conclude that several factors are involved in crown fire occurrence, and it is not possible to determine the specific role of each.

Topography

The Mack Lake Fire burned on the eastern edge of the Lower Michigan highlands, which are about 75 miles across. Average elevation is 1,250 feet (570 feet above Lake Michigan) and maximum elevations range from 1,500 to 1,700 feet. The fire burned on a plateau approximately 14 miles wide, extending 12 miles beyond the eastern edge of the highlands. The top of the plateau is a very shallow basin approximately 5 miles across, draining into Mack Lake. In a north-south cross section, the valley rises from 1,170 feet at Mack Lake to an average of 1,300 feet (maximum 1,470 feet) along the edges of the plateau. Going from west to east, the basin is nearly flat, rising from 1,150 feet along Big Creek to 1,250 feet.

The fire made its major run in a flat portion of a basin where many areas have elevational differences of less than 10 feet in a mile. The edges of the basin are rolling, with slopes of 20 to 30 percent and elevational differences of 30 to 70 feet. These changes no doubt resulted in local topographic effects, such as increased upslope rates of spread, greater fire intensity on southern exposures, and increased turbulence and spotting. They did not, however, significantly affect the overall behavior of the fire.

The basin has roads along a majority of section lines and secondary roads within many sections, breaking the area into square mile or smaller blocks. As with topographic effects, roads probably influenced local fire behavior. They were ineffective, however, in stopping or significantly slowing the fire (upper-left photo, back cover). The initial escape resulted from spots that jumped more than 200 feet across a two-lane highway (fig. 14). There are no significant wetlands or marshes in the basin which might have impeded the fire's progress. We therefore conclude that there were no topographic barriers to the spread of the fire, once it became established.

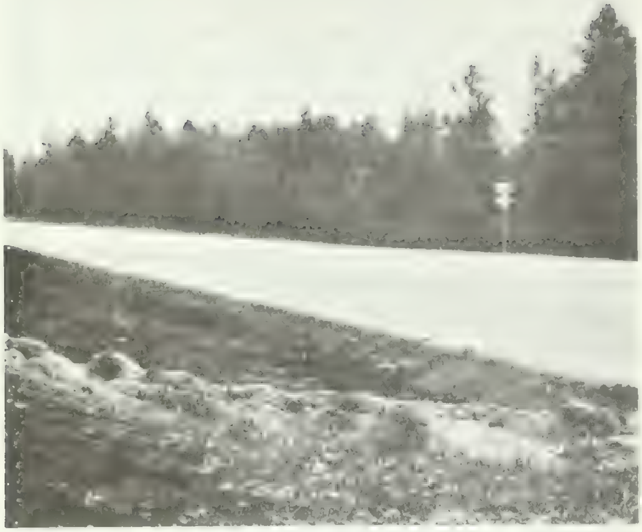

Figure 14.—*View from probable point of spotting to point of ignition, east of Highway 33 (50 feet to left of highway sign).*

FIRE PHENOMENA

Fire Chronology

An aerial photomosaic of the Mack Lake Fire (fig. 15) indicates the approximate position of the fire front at each time in the following chronology.

Between 1022 and 1026 (May 5)*[4]

The Crane Lake prescribed burn (fig. 16) was ignited. No unusual fire activity was noted for the first 45 minutes. The piled slash burned vigorously, with flame lengths of 10 to 15 feet, but flame lengths between the piles were only 6 to 12 inches (fig. 17). Although some spot fires crossed the control line, they were easily contained and firing resumed. During the next 45 minutes, three more spot fires occurred, one of which required a double plow line to contain.

*At 1206**

The prescribed fire spotted into standing jack pine timber adjacent to and upslope (26 percent) of the prescribed fire area (fig. 18). Being on the windward edge of a hill (fig. 19), the stand was exposed to the wind; this, coupled with heavier fuel loadings, including bracken fern, resulted in a much faster spread rate than had been experienced in the prescribed burn area. The fire spread eastward toward Highway 33, 675 feet away, with scorch heights ranging from 1 to 6 feet. A tractor/plow attempted to contain the spot between the prescribed burn and the highway (fig. 19).

*Between 1215 and 1230**

The fire spotted across Highway 33. This may have resulted from the burning slash piles or from the spot fire torching a small group of trees at the edge of the highway. The first spot across the highway had scorch heights of 2 to 4 feet and was contained at three-fourths of an acre. A second spot (225 feet from the fire, fig. 14), first noted at 15 feet in diameter, was attacked by a tractor/plow within 4 minutes of detection. At this time, considerable smoke was reported across Highway 33, hampering visibility. The spot torched some trees within 25 feet of the point of origin and then dropped to the ground in a narrow strip of mature jack pine. The fire boss recalled a sudden increase in windspeed at this time The fire entered an extensive sapling-sized jack pine stand and crowned within 100 feet of the point of origin (fig. 20). Surface fuel at the point of crowning was primarily sedge combined with pine litter and duff (table 5d).

Between 1232 and 1245**

The fire front was ½ mile east of Highway 33, and spotting at least ¼ mile ahead (fig. 21). The tractor/plow was now working the north flank. An armored tanker started following and eventually passed the tractor/plow. The tractor/plow operator was trapped shortly after being passed by the tanker. The tanker crew reported that they never saw the head of the fire, despite traveling at 4 to 6 mi/h while spraying water. Although the fire was on the ground close to where the crew was working (flame heights of 1 to 2 feet), torching and crowning were visible 100 to 200 feet inside the line (flame heights of 30 to 40 feet). The fire was described by the crew as turbulent with "heavy, roiling black smoke." The wind shifted direction several times and the fire frequently fingered in a northerly direction. The fire was reported to be "...very sensitive to wind. A slight change in wind direction and a hot flank immediately turned into a crowning head." The changes were described as instantaneous. In the words of the tanker operator, "I'm sure that the main head of the fire was heading east, but the flanks were acting like the head of many fires I've been on."

Wind data from Houghton Lake and patterns of unburned tree crowns give no indications of shor

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[4] *District log book entries are noted by an asterisk. Other times are estimates made by observers.*

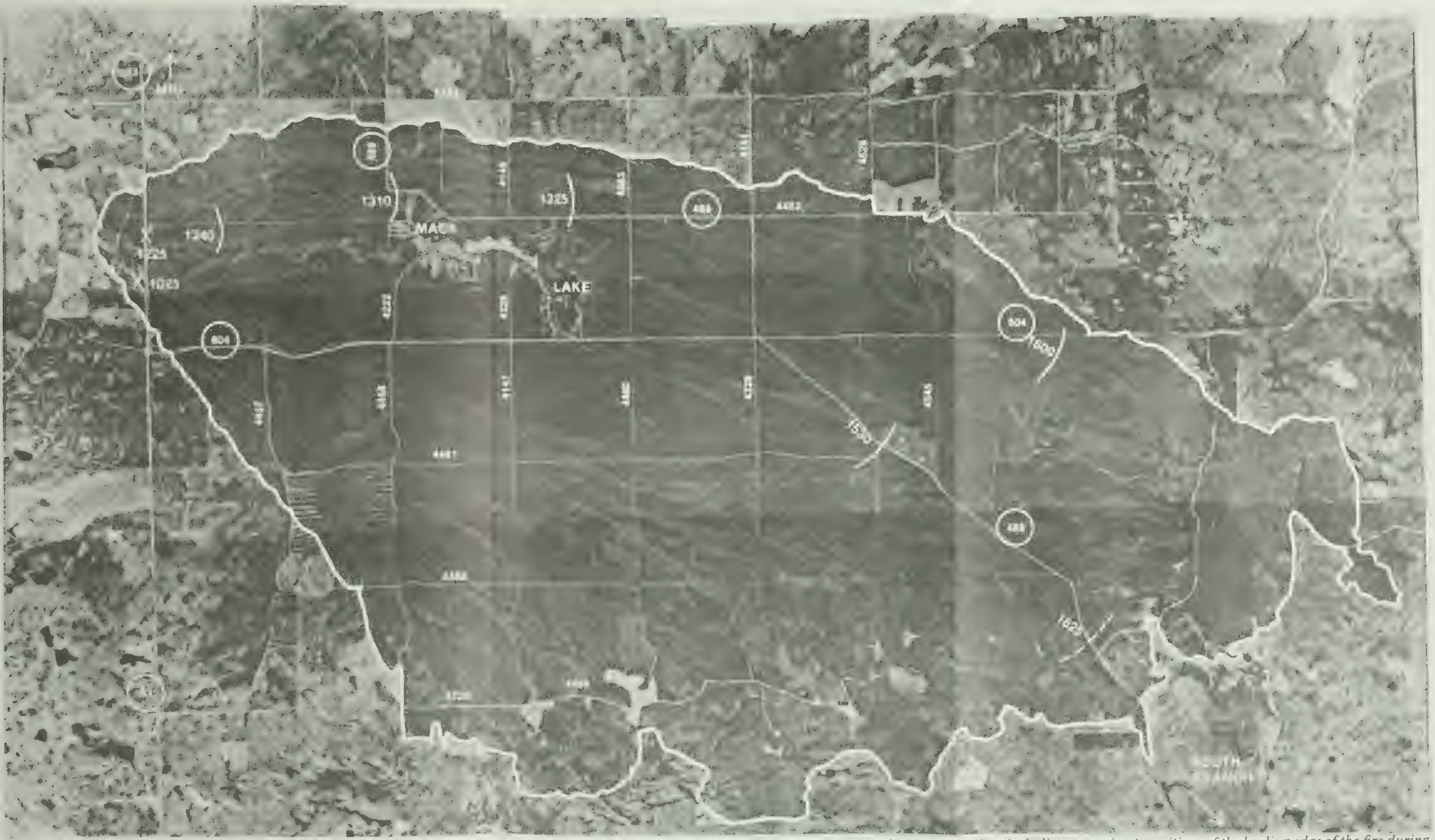
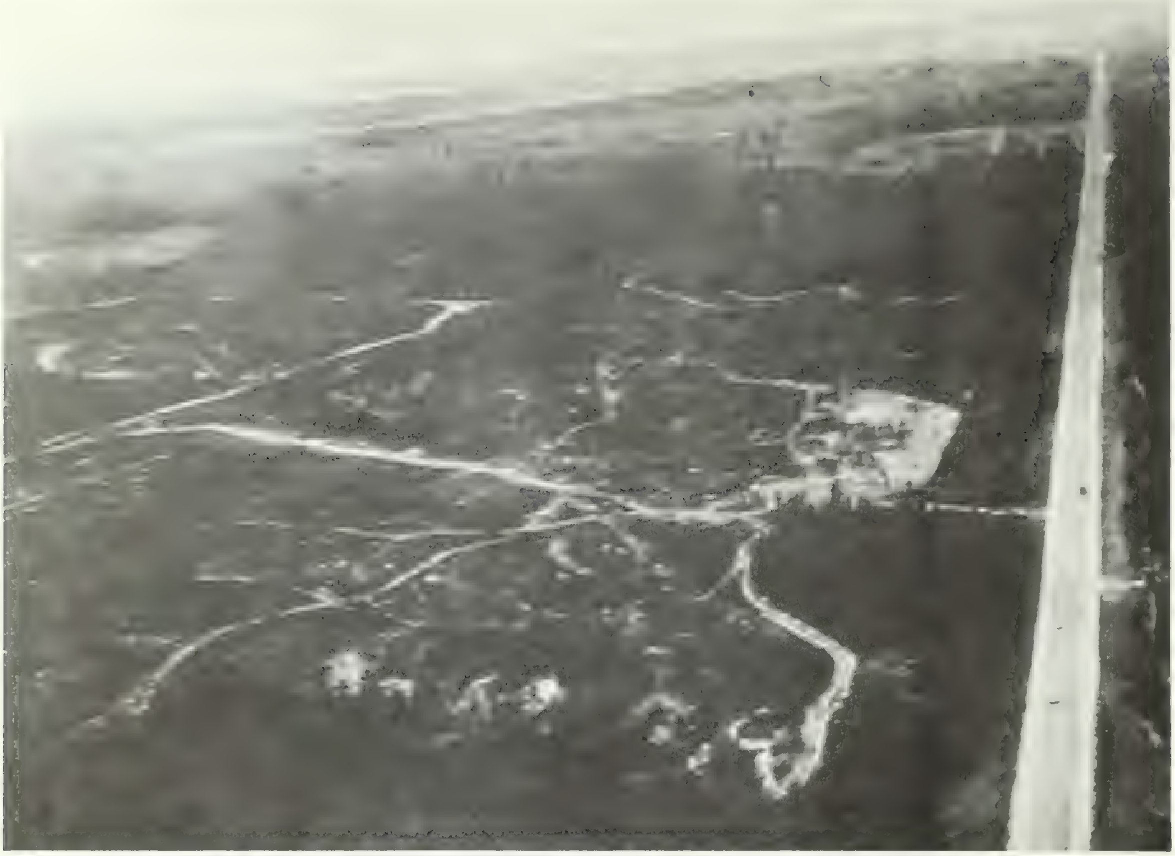


Figure 15.—*Area burned by the Mack Lake Fire, including approximate positions of the leading edge of the fire during the afternoon of May 5, 1980. Photo courtesy Huron-Manistee National Forest.*



gure 16.—*Aerial view (looking north) of Crane Lake prescribed burning unit. Ignition began at intersection of north-south fire line and east-west skid trail (right-center). Firing proceeded northward (note unburned area east of fire line) and around island of standing timber. Escape (west of Highway 33) was into standing timber just beyond island.*

—*Early stage of prescribed fire. Note con-*
fire intensity between piles and open areas.
ourtesy Huron-Manistee National Forest,
nger District.

Figure 18.—*View of standing timber into which initial escape occurred (top of hill in background).*

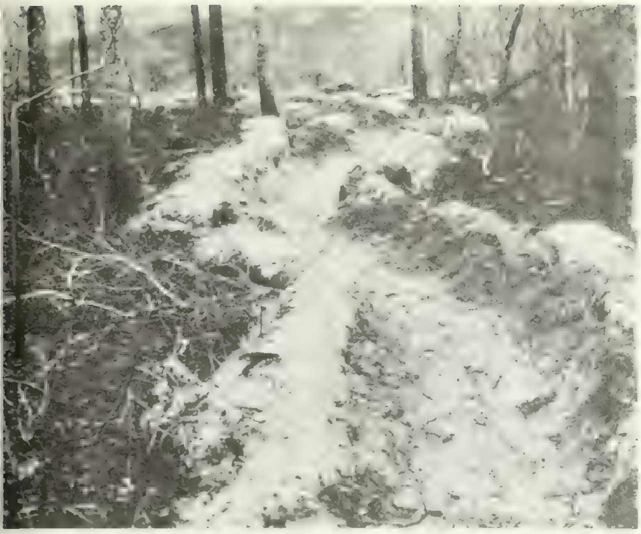


Figure 19.—*Plow line that failed to hold initial escape. Note openness of stand into which fire spotted.*

duration shifts of the ambient wind, implying local fire-induced turbulence. Subsequent examination of the area strongly indicated that a horizontal roll vortex (see page 24) formed along the flank where the crew was working (fig. 22). The crew was working on the north side of an unburned crown strip. The crew's description of fire conditions (1- to 2-foot flame

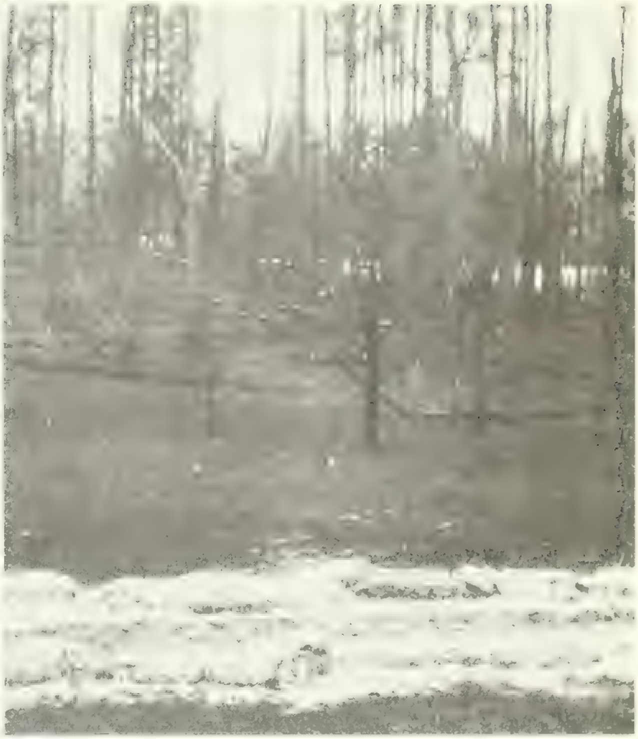


Figure 20.—*View of escape area (east of Highway 33, in background). Fire crowned in sapling-sized timber in foreground. Note plowline in foreground.*

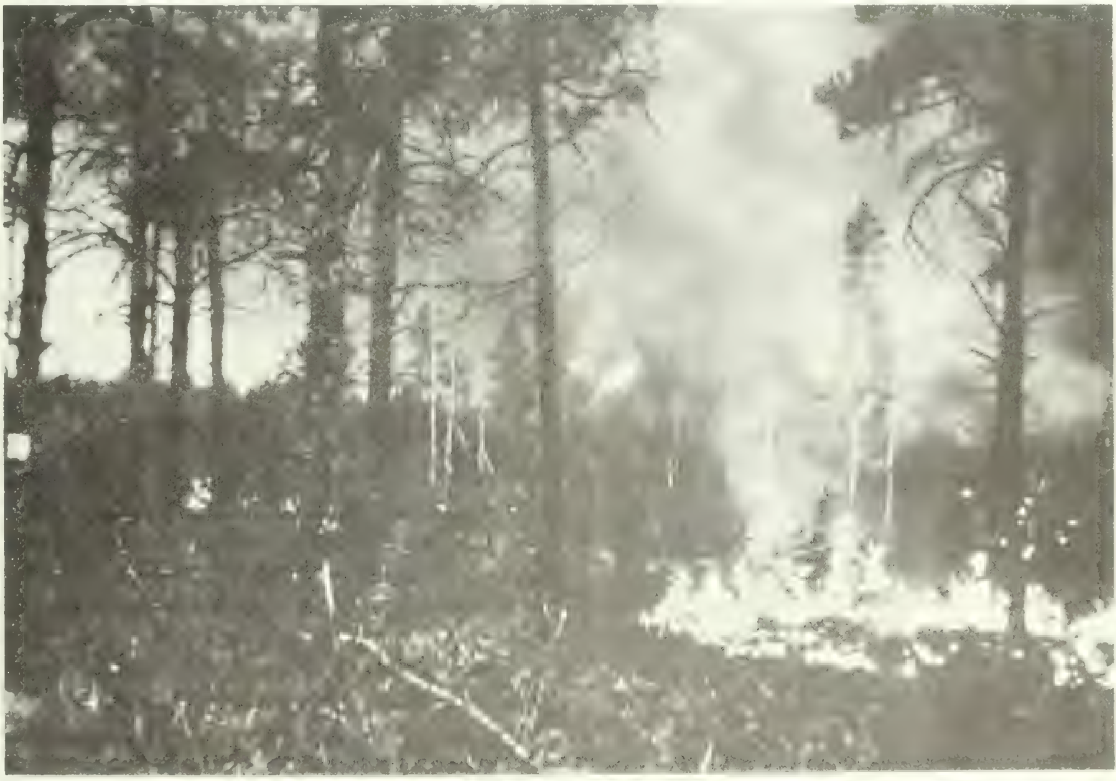


Figure 21.—*Two spot fires along north flank, ¼ mile ahead of main fire front. (Second spot is behind trees at left.) Photo courtesy of Huron-Manistee National Forest, Mio Ranger District.*

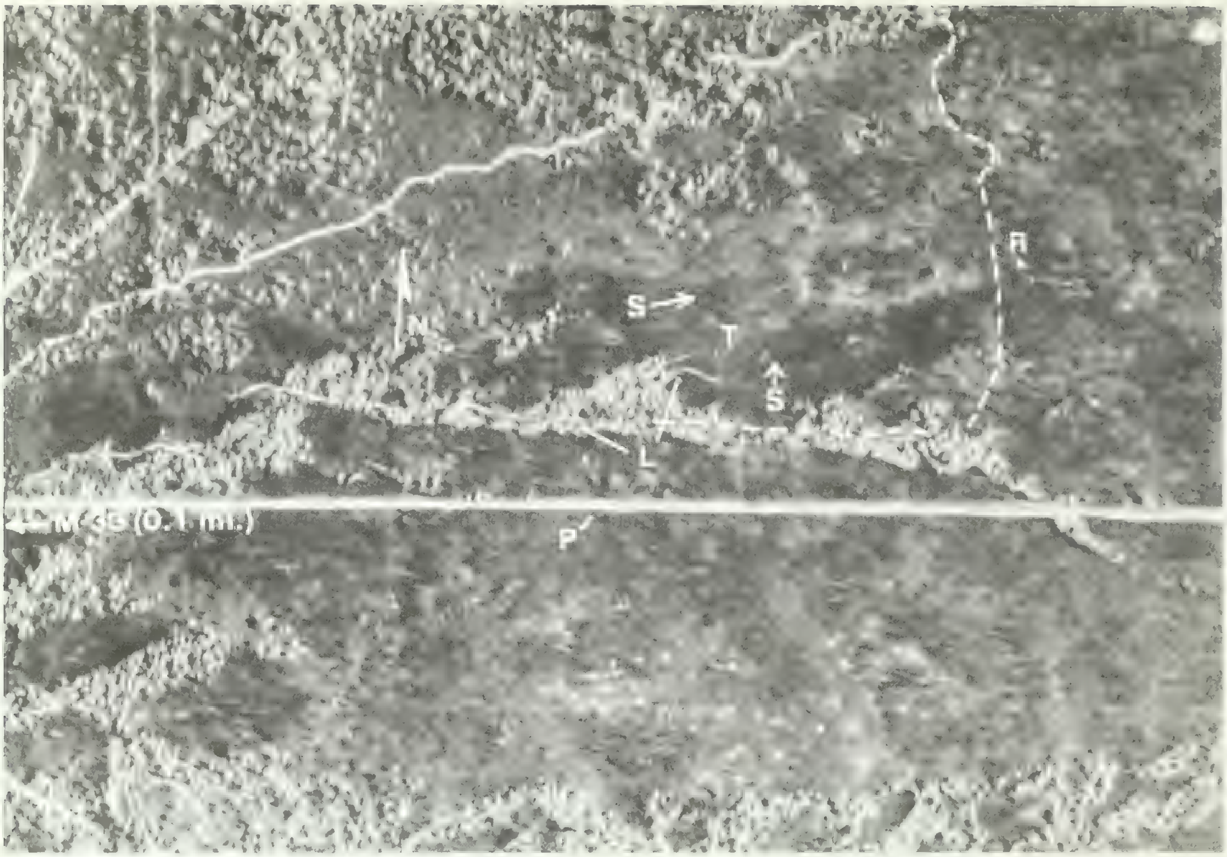


Figure 22.—*Aerial photograph of the fatality area. L = tractor plow line, (three subsequent plow lines can be seen in the northeast quadrant of the photo), N = north, P = power line and gravel road, R = approximate route of leading tanker unit, S = fire spread direction, and T = final location of tractor/plow unit. Photo courtesy Huron-Manistee National Forest.*

heights and extreme turbulence) is consistent with a strong downdraft carrying firebrands and igniting a line of fire, along which they were working (see fig. 26). Their description of 30 to 40 foot flame heights and crowning 100 to 200 feet further inside the burning area is consistent with a vortex updraft. The evidence of a northward moving crown fire approximately 100 feet east of the point where the tractor abruptly turned northward is consistent with a local north wind resulting from the downdraft portion of a vortex. There is also evidence of an eastward moving crown fire (originating from spots which crossed the line behind the tractor) approximately 200 feet north of the tractor's final position. Once established, the latter crown fire was presumably beyond the influence of the vortex and responded to ambient winds. The tractor/plow and operator were trapped between the two fires while the tanker (approximately 100 yards ahead) was able to turn northward and escape.

Because other scenarios could be reasonably consistent with the physical evidence, we cannot prove that our hypothesis is what actually transpired. However, all other possibilities we considered do nc
appear to agree with the physical evidence as we
as that postulated here. Therefore, although we hav
described what, in our opinion, is the most likel
sequence of events, further research on the forma
tion of horizontal roll vortices will be needed to cor
firm or refute our hypotheses.

*At 1310**

The fire crossed County Road 489 (1½ miles eas
of the last reported position). It was approaching th
village of Mack Lake, which had been evacuate
Photographs (cover) indicate flame heights of twic
the height of the trees (20 to 30 feet). The fire bos
reported that "a wall of fire" was approaching th
village. He was "impressed with its consistency." H
reported flame heights 20 to 30 feet above the tree
These observations suggest flame heights rangin
from 40 to 60 feet (back cover—bottom). The fi
was still spotting at least ¼ mile ahead (spot on edg
of lake—front cover photo).

*At 1325**

The fire had passed through the village of Mack Lake. Forty-four homes and cottages (about one out of three) were destroyed (fig. 23). Although a study was not conducted, a general impression is that homes with mowed lawns and some distance between them and the jack pine forest survived. Those in minimal clearings with natural vegetation and/or with firewood piled adjacent to the house did not. This is consistent with findings after other large wildfires (Fischer and Books 1977).

By this time, the fire was ½ mile east of Forest Service Road 4146 (1½ miles east of the 1310 position). At about this time, a second report indicated that the fire had spread along County Road 604 from Forest Service Road 4458 to 4460 (2 miles) in 15 minutes. These observations indicate spread rates of 6 to 8 mi/h—the fastest reported spread rates during the fire's run. One observer remarked that it was "notably warmer" when the fire was still ½ mile away. The flames were described as similar to movies of the sun, with isolated balls of flame in the air. Another observer noted that, "Following the crown fire, unburned ground fuels ignited and burned in all directions." This could imply that during the major run, the crown fire was independent of the ground fire. This observation could also describe a crown fire which gained momentum from spot fires and raced ahead of the surface fire for some distance before dropping back to the ground. Surface fuels ignite from material that drops from the burning overstory. Such "semi-independent" crown fire behavior was reported on the Gaston Fire in South Carolina.[5] It is in the areas burned during this period that the largest unbroken areas of crown fire are found.

At 1530

The fire was at the junction of County Road 489 and Forest Service Road 4461 (3 miles east of the 1325 position). The wind had shifted to west-northwest and the fire was now spreading east-southeast on a wide front. Although the fire was still spreading rapidly, the rate of advance had slowed slightly. The three back cover photographs were taken during this interval.

At 1600

The fire was ½ mile east of Forest Service Road 4527 along County Road 604 (4 miles east of the 1325 position). This sector of the fire had passed from jack pine to hardwoods and was burning on the ground. The northeast corner of the fire had become a flank, and control actions were becoming effective along this portion of the perimeter. Most of the front, however, was still actively crowning in jack pine.

*At 1825**

The fire was reported to be 4 to 5 miles northwest of the community of South Branch. Since the final perimeter was 5 miles northwest of South Branch, the fire was perhaps 5½ miles away at this time. This is 1½ miles from the 1600 position. The wind had further shifted to north-northwest and the fire was now spreading south-southeast. What had been the southern flank was now the fire front. Although most of the fuel burned during this period was jack pine, the crown fire appears to have weakened. A random sample of an aerial photomosaic (fig. 15) indicates that in the area burned during this period, an average of 30 percent of the crown foliage was not consumed. Since both wind and fuels remained constant, we presume that this change largely reflected increased relative humidity which, by 1800, had risen to 55 percent. During this period, video tapes of the fire taken along Highway 33 (at the rear and flank) show backfire flame heights of 12 to 18 inches in jack pine surface fuels. Flame heights in 2- to 2½-foot-deep fresh slash were 5 to 10 feet, however. Thus, although the fire had slowed, it still presented control problems, particularly where fuel loadings were high. High crown scorch heights of isolated red and jack pine trees in the hardwood areas attest to the fact that even though the fire burned on the ground, it was still moderately intense.

By 2400

The fire spread an additional ½ mile to the east and south, primarily on the ground, through hardwood stands. Mechanized equipment could now work effectively on all sections of the perimeter.

By 0600 (May 6)

The fire had essentially stopped spreading. Suppression forces had constructed 15 miles of control line.

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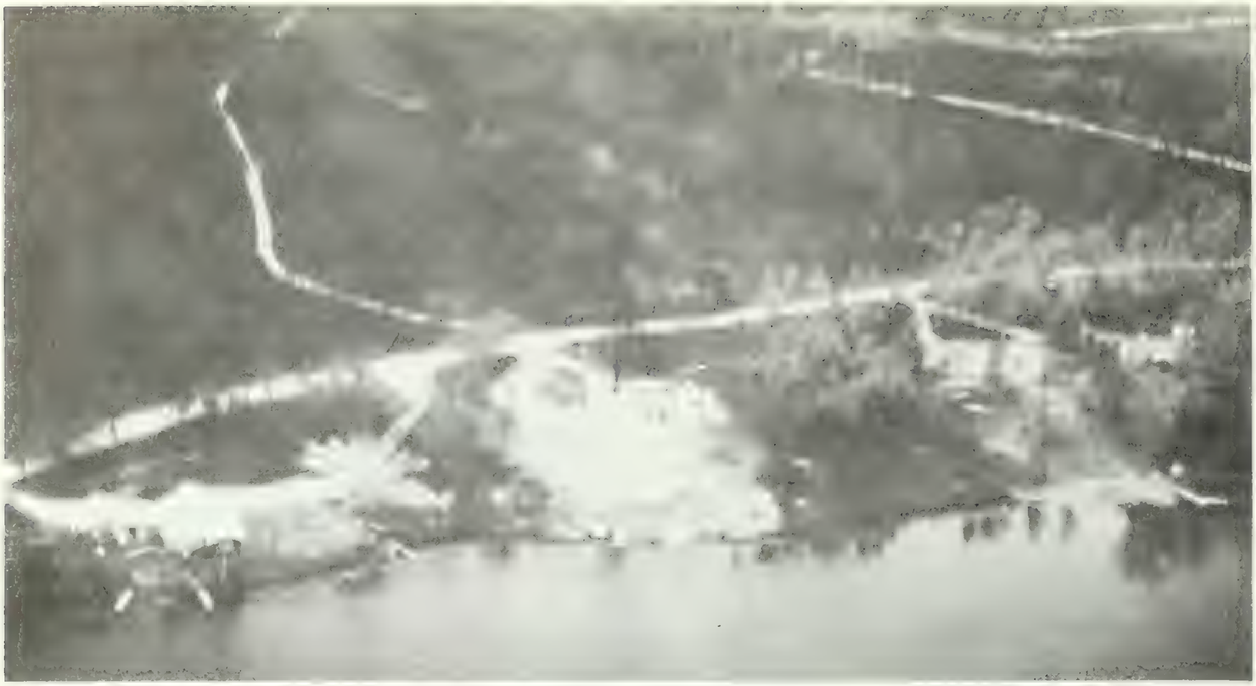
[5] *Wade, Dale. Research Forester. U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station, Macon, GA; personal communication.*



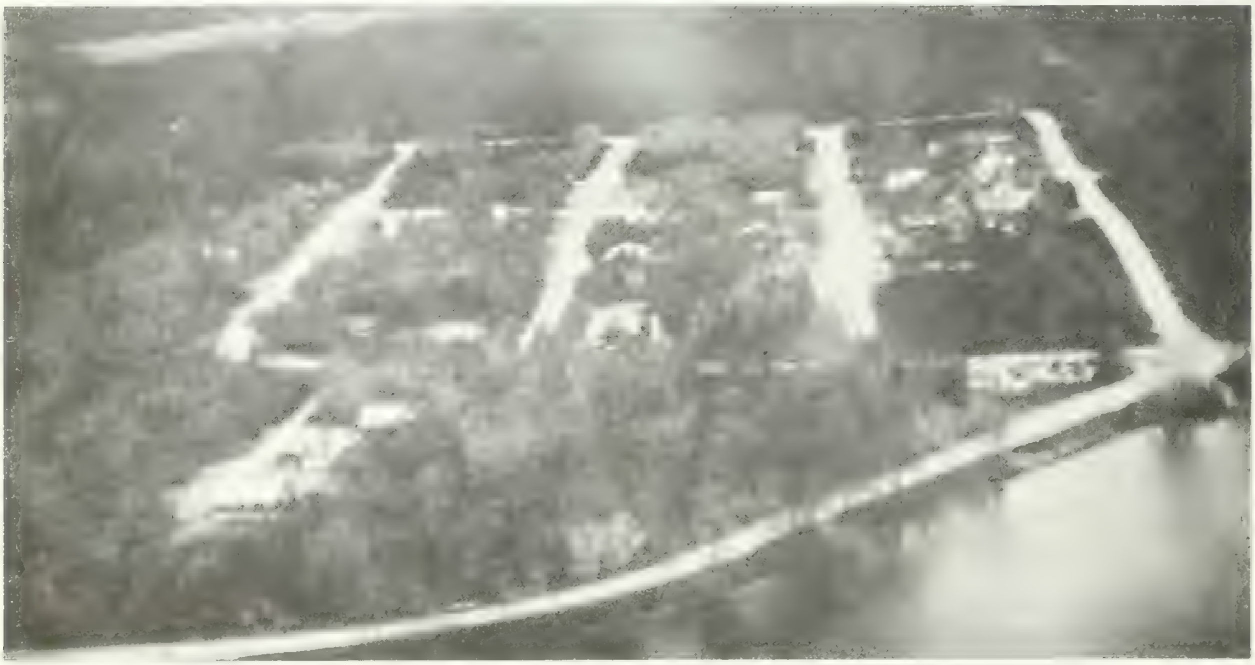


Figure 23.—*Four homes at Mack Lake—two destroyed and two saved. The two homes on the left are shown on the front cover just before the fire passed (top). The village of Mack Lake after the fire. About one structure in three was destroyed (bottom).*

By 1800

The fire was contained at 23,830 acres, with 35 miles of control line. There was no significant increase in acreage burned during the day. Little difficulty was experienced in burning out from plowed control lines.

It is important to note that during the 4 days following passage of the same dry cold front that affected the Mack Lake Fire, a forest fire in Alberta increased from 20,000 to 150,000 acres in size (Alexander *et al.* 1983). Therefore, it is reasonable to assume that if the Mack Lake Fire had not run out of jack pine, the total area burned would have been significantly larger.

Fire Behavior

We calculated or estimated 12 parameters describing the behavior of the Mack Lake Fire. They are divided into two categories: size (table 6a) and energy release (table 6b). The first group includes rate of spread, length of head, length of perimeter, rate of perimeter growth, area, and rate of area growth. The second group includes fireline intensity, frontal energy release rate, total energy release rate, total energy released, fuel consumption, and total fuel consumed. Flame length data for the fire were not available. Although a few flame heights were reported or could be scaled from photographs, the information was too sketchy to include in table 6. Each parameter was determined for eight intervals during the fire's history to coincide with the fire chronology.

When the specific endpoints of an interval are not known (e.g., between 1022 and 1026), the average denotes the beginning or end of the fire behavior interval (e.g., 1024). The two intervals 1325-1530-1600 were combined into one in table 6. Computational techniques are described in Appendix I.

Spread and Intensity

During its major run (1230 to 1600) the Mack Lake Fire spread 7.5 miles at an average rate of 2.1 mi/h. This rate is similar to those of other major fires. The Sundance Fire in Idaho spread 15.5 miles in 9 hours (1.7 mi/h, Anderson 1968), and the Air Force Bomb Range Fire in North Carolina covered 12 miles in 7.25 hours (1.7 mi/h, Wade and Ward 1973). Red Lake 31 in Ontario spread 10 miles in 5 hours (2 mi/h, Stocks 1975), the Badoura Fire in Minnesota spread

Table 6a.—*Mack Lake Fire behavior (size)*

Time	Duration	Rate of spread[1]		Length of head[2]	Length of perimeter[2]	Rate of perimeter growth[1]	Area[2]	Rate of area growth[1]
	h:min	mi/h	ft/sec	mi	mi	mi/h	acres	acres/hour
1024–1206	1:42	—	—	—	0.9	—	20	—
1206–1222	0:16	0.45	0.66	0.06	1.3	1.5	23	11
1222–1238	0:16	1.9	2.8	.25	2.2	4.6	80	300
1238–1310	0:32	2.8	4.1	1.0	6.5	7.0	1,000	1,700
1310–1325	0:15	[3]7.0	[3]10.3	1.5	10.0	14.0	3,000	8,000
1325–1600	2:35	1.5	2.2	3.5	20.0	3.9	9,000	2,300
1600–1825	2:25	.6	.8	6.5	24.0	1.4	20,000	4,000
1825–2400	5:35	.09	.13	7.0	[4]34.0	[5].25	[6]23,000	550

[1] Average for the period.
[2] At the end of the period.
[3] Average of two observations.
[4] Based on a final perimeter of 35 miles.
[5] Based on what the calculated perimeter would have been (25.4 miles).
[6] Based on a final size of 23,830 acres.

Table 6b.—*Mack Lake Fire behavior (energy release)*

Time	Fireline intensity	Frontal energy release rate	Total energy release rate	Total energy released	Fuel consumption	Total fuel consumed
	Btu/ft/sec	Btu/sec[1]	Btu/sec	Btu	Tons/sec	Tons
1024–1206	—	—	1.15×10^6	6.24×10^9	0.09	520
1206–1222	[2]1,350	2.14×10^5	2.74×10^5	2.63×10^8	.02	20
1222–1238	8,100	6.61×10^6	7.56×10^6	7.26×10^9	.63	600
1238–1310	11,800	3.92×10^7	6.10×10^7	1.18×10^{11}	5.1	9,770
1310–1325	[3]29,700	1.98×10^8	2.83×10^8	2.55×10^{11}	23.5	21,230
1325–1600	6,300	8.38×10^7	8.22×10^7	7.64×10^{11}	6.8	63,700
1600–1825	2,300	6.09×10^7	1.62×10^8	1.40×10^{12}	12.6	115,500
1825–2400	[4]530	1.89×10^7	3.39×10^7	6.82×10^{11}	2.8	[5]55,920
Total				3.32×10^{12}		267,260

[1] Based on average head length during period: (final + initial)/2.
[2] Foliage not consumed.
[3] Average of two observations.
[4] Fire burned in hardwoods during this period.
[5] Based on a final size of 23,830 acres.

7.5 miles in 4.75 hours (1.6 mi/h, Minnesota Department of Conservation 1959), and fire DND-4-80 in Alberta spread 11 miles in 5 hours (22 mi/h, Alexander *et al.* 1983). Although 2 mi/h is an impressive sustained run, faster sustained rates, although rare, have occasionally been recorded: the Lesser Slave Lake Fire in Alberta (4 mi/h for 10 hours, Kiil and Grigel 1969), the Mullen Fire in Nebraska (6 mi/h for 5 hours),[6] the Big Scrub Fire in Florida (6 mi/h for 3 hours, Anderson, in press). The peak rates of spread for the Mack Lake Fire (6 to 8 mi/h) equal the peaks for the Sundance Fire and the Badoura Fire. Faster peak rates of spread could not be found in the literature.

The fast spread rate of the Mack Lake Fire resulted from three factors: relative humidity averaging 23 percent, windspeed averaging 15 mi/h and gusting to 30 mi/h, and dense pole-sized jack pine. Between 1600 and 1800, relative humidity rose from 37 to 55 percent. At the same time, the fire moved from jack pine into hardwoods. Both factors contributed to the significant reduction in rate of spread during the evening hours (0.6 mi/h).

During its major run, the Mack Lake Fire had an average fireline intensity of 8,800 Btu/ft/sec. Given the variability associated with estimating fire intensity, this is similar to the averages for Red Lake 31 (8,500 Btu/ft/sec), the Sundance Fire (7,300 Btu/ft/sec), and the Bomb Range Fire (6,000 Btu/ft/sec). Note, however, that intensity at Mack Lake is averaged over only 3.5 hours, compared with 5 to 9 hours for the other fires. Although the Lesser Slave Lake Fire had a reported average intensity of 25,000 Btu/ft/sec, duff burn depths of up to 6 inches were also reported. Because a significant portion of this material would have been consumed after the fire front passed, the Slave Lake intensity is not comparable to that of the Mack Lake Fire. Peak fireline intensity (average of two 15-minute observations) for the Mack Lake Fire was 29,700 Btu/ft/sec. This approximates what some authorities consider an upper intensity limit for a moving crown fire—30,000 Btu/ft/sec (Byram 1959). The maximum 1-hour average fireline intensity (1225 to 1325) for the Mack Lake Fire was 15,500 Btu/ft/sec. This is less than the maximum 1-hour average for the Sundance Fire (22,500 Btu/ft/sec) and the Bomb Range Fire (18,100 Btu/ft/sec).

Observed fire behavior was compared with predictions from the Albini (1976) fire behavior models. Model inputs were: effective windspeed, 15 mph; slope, 0 percent; dead fuel moisture, 7 percent; and live fuel moisture, 100 percent. During the initial escape west of Highway 33 (1206 to 1222) the fire burned on the ground, under a closed jack pine canopy. This group of trees was about 3 acres in size and exposed to the wind on three sides. Model 2 (open timber, grass understory) yielded a 0.9-mi/h rate of spread, an 8-foot flame length, and a 500-Btu/ft/sec intensity. Model 10 (closed timber, litter, understory) yielded a 0.2-mi/h rate of spread, a 6-foot flame length, and a 300 Btu/ft/sec intensity. Because the stand might best be described as partially open, the fact that the observed rate of spread (0.45 mi/h) lies between the two predictions seems reasonable.

That the models underpredicted calculated intensity (1,350 Btu/ft/sec) is not as significant as it might appear. First, predictions are well beyond the limit of manual control (100 Btu/ft/sec) and, in the case of model 2, approaching the limit where spotting would be expected to present serious control problems for mechanical equipment (600 Btu/ft/sec, Albini 1976). Second, we determined that 7.3 tons of surface fuel per acre were consumed, and we assumed that it was all consumed by the fire front. Although this assumption is reasonable for the Mack Lake Fire, some undeterminable portion of the material was no doubt consumed after the flaming front passed. Thus, actual fireline intensity was somewhat less than indicated in table 6b. Finally, fuel model 2 incorporates only 2.5 tons/acre of material likely to be consumed by the fire front, and fuel model 10 includes 3.3 tons acre. Clearly, doubling or tripling fuel loading significantly increases intensity.

Once a fire crowns, the timber understory models no longer apply. The closest approximation to a jack pine crown fire is obtained with model 4 (chaparral 6 feet). This model predicted a spread rate of 1.6 mi h, 24-foot flame lengths, and a fireline intensity of 6,000 Btu/ft/sec. Considering the apparent differences between jack pine and chaparral, this is a surprisingly good prediction of what happened. The higher loading of 1- and 10-hour and live fuels in the chaparral model (14 tons/acre) relative to jack pine is offset by a tenfold increase in foliage bulk density (0.04 lbs/ft^3, Albini 1976). Based on the relative magnitude of the differences, it is reasonable to assume that the much lower bulk density of jack pine foliage will predominate, resulting in faster spread rates and higher intensities for jack pine crown fires than are predicted by the chaparral model. Note however, that using a windspeed of 18 mi/h (rather than 15) yields a predicted 2 mi/h spread rate, 28-foot flame length, and a fireline intensity of 9,000 Btu/ft/sec.

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[6] *Anderson, Hal. Research Forester. U.S. Department of Agriculture, Forest Service, Northern Forest Fire Laboratory, Missoula, MT; personal communication.*

Convection and Spotting

The distinction between a wind-driven and a convective fire is an important and sometimes critical fire behavior characteristic. To determine which process predominated on the Mack Lake Fire, we examined the smoke column and analyzed the energy balance between the fire and the wind field. Throughout much of the afternoon, the smoke column rose at a moderate angle (45°) up to an estimated altitude of 5,000 feet. The middle portion rose at a steeper angle (60°) to an estimated 10,000 feet. This was topped by an apparent cumulus cloud which we estimated topped off at 15,000 feet (fig. 24). In Oscoda (35 miles downwind from the fire) "a definite wood smoke smell in the air" was reported, and ash particles ¼ to ½ inch in diameter were observed.[7] A very light rain fell with drops "high in particulate matter." (This had to be condensation from the convection column as the sky was otherwise clear.) The Au Sable River near Oscoda was "covered with ash" (several visible pieces per square foot).

Using Byram's (1959) energy balance equations (Appendix I), we determined the rate of flow of kinetic energy in the wind field (P_w) and the rate at which thermal energy is converted to kinetic energy in the convection column (P_f). Results are given in table 7. Byram (1959) states "extreme fire behavior and blowup characteristics occur when P_f exceeds P_w for a considerable height above the fire—usually at least 1,000 feet and more, often greater than 3,000 or 4,000 feet."

From table 7, P_f exceeded P_w at the surface throughout the afternoon. Because P_w is proportional to the cube of the windspeed, however, increasing windspeed associated with increasing altitude normally results in $P_w > P_f$ at some distance above the ground. During the first hour, the energy parameters equalized at between 1,000 and 2,000 feet. It is not known whether this is sufficient height for development of a vertical structure with free convection. In any case, the 35 mi/h low-level jet overpowered the convection column between 2,000 and 3,000 feet.

For a brief period (1310-1325) the fire's energy was sufficient to overcome that of the wind field. It was during this period that the most extreme spread rates and behavior were noted. Although visual observations of the convection column are not available, we may assume that true blowup conditions prevailed. Starting at 1400, surface windspeed increased to 15 mi/h. Most likely, turbulence had transferred some of the momentum of the low-level jet downward. This resulted in $P_w = P_f$ at altitudes below 1,000 feet. Therefore, for the remainder of the day, the fire was essentially wind driven and two dimensional.

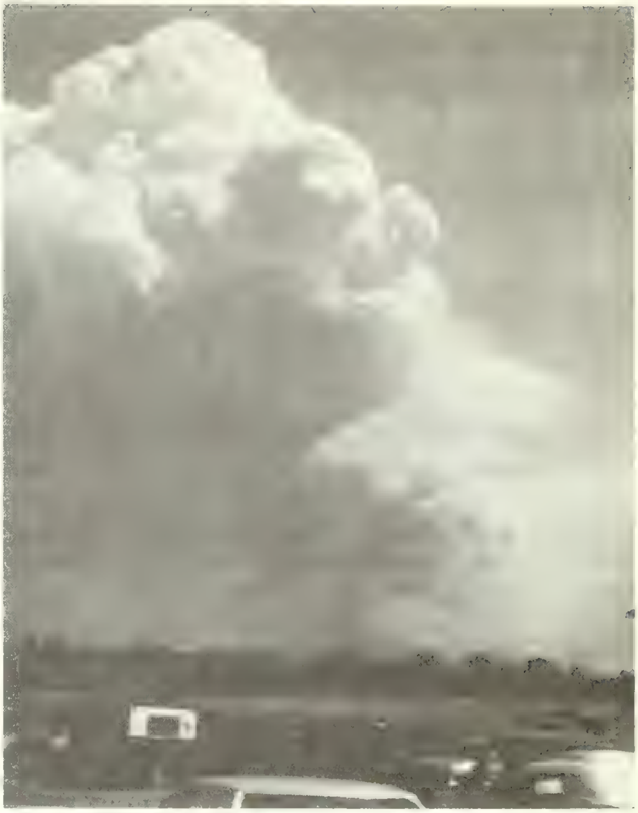

Figure 24.—*Smoke column from the Mack Lake Fire. Photo courtesy of Michigan Department of Natural Resources.*

The initial escape east of Highway 33 spotted 225 feet from the prescribed fire. During its run, the fire was observed spotting at least ¼ mile ahead (front cover, fig. 21). Albini (1979) published a model which predicts spot fire distances from burning trees. Using jack pine, 5-inch d.b.h., 25-foot tree height, 25 trees burning simultaneously, and 15 mi/h windspeed, his model predicts a 1/3-mile maximum spotting distance during the major run. Using conditions in the vicinity of the torching trees during the initial escape west of Highway 33 (3-inch d.b.h., 15-foot tree height, five trees burning and 10 mi/h windspeed), the model predicts a 1/10-mile maximum spotting distance. Thus, the model's spotting predictions are in excellent agreement with observations on the Mack Lake Fire.

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[7] *Grieve, Gerald. Fire Control Officer, Michigan Department of Natural Resources; personal communication.*

Table 7.—*Wind field and convection column energy balance for the Mack Lake Fire*

		P_w[1]					
		Altitude above surface (ft)					**Altitude where**
Interval	P_f[1]	**0**	**1,000**	**2,000**	**3,000**	**4,000**	$P_f = P_w$
1206–1222	12	2	9	147	156	86	1,100
1222–1238	57	1	6	129	138	74	1,500
1238–1310	85	1	5	119	127	67	1,800
1310–1325	208	0	1	79	85	41	—
1325–1600	45	[2]9	[2]48	134	143	78	[2]900
1600–1825	16	[2]11	[2]54	146	155	86	[2]200

[1] ft-lb/sec/ft^2.

[2] Based on a surface windspeed of 15 mi/h after 1400 (table 2) and assuming a linear increase to 2,000 feet.

Although even a ¼-mile-wide fuel break might not be an effective fire barrier under such conditions, it could yield several fire suppression benefits, particularly if composed of less flammable hardwood species. It could reduce rate of spread and intensity to suppressible levels and provide a relatively safe area from which to make a stand. In some areas, the effective width of a break could be increased by backfiring. Given typical spotting distances, however, even wide fuel breaks would have to be coupled with extensive downwind patrolling to insure a reasonable chance of holding a crown fire.

Horizontal Roll Vortices

An important characteristic of the Mack Lake Fire is the numerous strips of unburned (but generally scorched) tree crowns (fig. 15). Wade and Ward (1973) noted similar unburned crown patterns on the Air Force Bomb Range Fire and the Exotic Dancer Fire in South Carolina. They summarized existing hypotheses about possible causes of the patterns:

1. A fluctuating wind direction could result in decreased intensity along one flank and increased intensity along the other. This could result in alternate backing and flanking behavior. (On the Mack Lake Fire, repeated shifts of 160° would have been needed to account for the physical evidence. No such shifts in ambient wind direction were observed.)
2. Windspeed could periodically decrease to less than that necessary to sustain a crown fire. (There is no evidence of significant ambient windspeed lulls during the fire's run, nor would this account for opposite spreading fires.)
3. A two-dimensional, wind-driven fire ($P_w > P_f$) could advance rapidly into new fuels, increase in intensity, and become three dimensional ($P_f > P_w$). As the fuel burns out, P_f is reduced and the wind again drives the fire. This requires that the fire act as a unit. (We do not believe that this process could account for several continuous 4- to 7-mile-long unburned crown strips noted on the Mack Lake Fire.)
4. Spotting ahead of the fire would result in secondary fires which, as they backed into the main fire, would increase in intensity. (Although this could account for random pockets of unburned fuels, it could not account for the regular banding pattern.)

Because existing hypotheses could not completely account for the physical evidence found on the Mack Lake Fire, we propose an alternate hypothesis. The evidence is strong that unburned crown strips result from downward-moving streams of air (fig. 25). The latter are likely the result of horizontal roll vortices (HRV), a form of Bénard cell (fig. 26). Such cells are well documented in the atmosphere. They produce cloud "streets" in the atmosphere (Kuettner 1959) and long parallel systems of sand dunes in deserts (Bagnold 1952). The cell has been described as helical in the atmosphere, but it is believed that the same air or entrained particles will make repeated rotations.

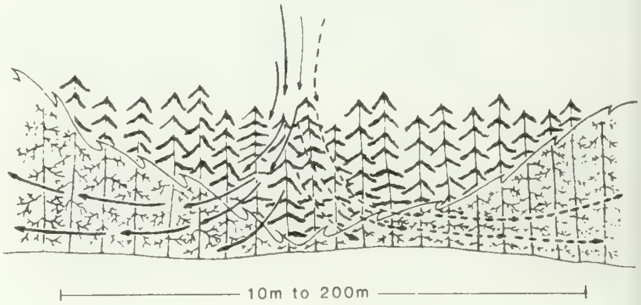

Figure 25.—*Hypothesized action of strong downdraft of air resulting from horizontal roll vortex. The downward moving stream of air could contain firebrands that would start a line of spot fires that would be blown in opposite directions.*

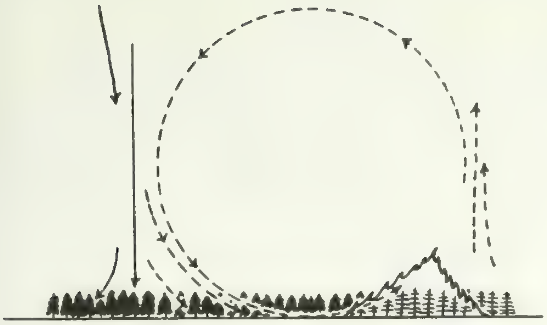

Figure 26.—*Simplified hypothetical cross section of a single horizontal roll vortex, suggesting possible entrainment of outside air. There is also an upward flow due to buoyant forces, which may mask the vortex circulation. The exact location of the vortex relative to the fire perimeter is not known.*

In a crown fire, the vortex should form in the shear zone between the ambient wind and the convective updraft along the edge of the fire (fig. 27). Although the vortex should appear as a horizontal smoke roll along the fire's flanks, the exact location of the vortex relative to the fire perimeter is not known. We examined video tapes of the Mack Lake Fire smoke column[8] and found what appeared to be two horizontal roll vortices. We estimated one on the northern flank to be 2 miles long and ¼ mile wide, but poor viewing angle and lack of ground definition precluded estimates of the dimensions of the second vortex on the southern flank.

Countryman (1968) found downward air motion over a fire, although the pattern of vertical flow was not well organized. Chandler *et al.* (1963) noted that several observations have been recorded of wind blowing outward from large fires. Schaefer (1957) described a large counterclockwise-rotating (looking downstream) Bénard cell 1 mile in diameter that acted as a lateral spread mechanism on the 1956 Dudley Lake Fire in Arizona. The smoke-outlined cell was reported to have remained as a coherent mass 300 miles downwind from the fire. We examined film from the Dudley Lake Fire which clearly showed a circulating air flow, including downward movement. Recently, Luti (1980) demonstrated that the *k-e* 2-equation turbulence model yields a horizontal circulating air pattern as a dominant feature along the forward and rear perimeters of a mass fire.

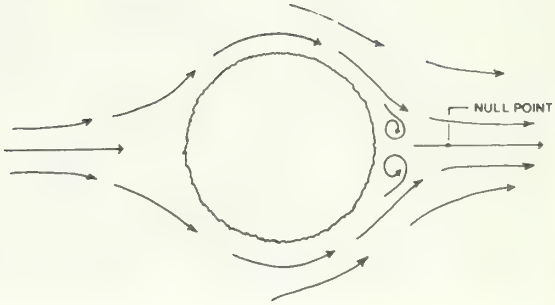

Figure 27.—*View (looking down) of a fire acting as a single unit, indicating location of shear zone along perimeter (from Countryman 1968).*

All postfire observations and evidence support the HRV hypothesis. Some strips are isolated and narrow (fig. 28 (top), foreground) and some are broad and grouped (fig. 28 (top), background), with green crown foliage visible in the center. The width of individual strips varies from 30 to 650 feet. Most strips were reasonably straight but a few curved inward toward the direction of major fire activity (fig. 28 (bottom)). When viewed from the air, one side of many strips was irregular, implying a fire in the early stages of crowning, while the opposite side appeared smooth, suggesting a well-developed crown fire (figs. 22, 28 (top)).

The unburned crown strips were most often parallel, although clusters of strips diverged (usually near the fire's origin) or converged (usually near the fire's termination—fig. 15). Distance between parallel strips ranged from 150 to 2,800 feet. The unburned tree-crown strips crossed roads and gently rolling terrain, while essentially maintaining their identity, often for 2 to 4 miles, and in one case, over 7 miles.

Tree trunk scorch height resulting from wildland fires is highest on the downwind side. Ground examination of the understory in the unburned crown strips invariably disclosed the low-charred sides of tree trunks facing each other. The char pattern was generally less evident in the direction toward which the fire was spreading (fig. 29 (top)) than in the direction from which the fire had come (fig. 29 (bottom)). Char height was generally 1 to 3 feet high on the inside of the tree trunks and 5 to 10 feet on the opposite side (160° apart). This implies that the fire spread in opposite directions with some forward

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[8] *Provided by television station WBKB-TV, Alpena, MI.*

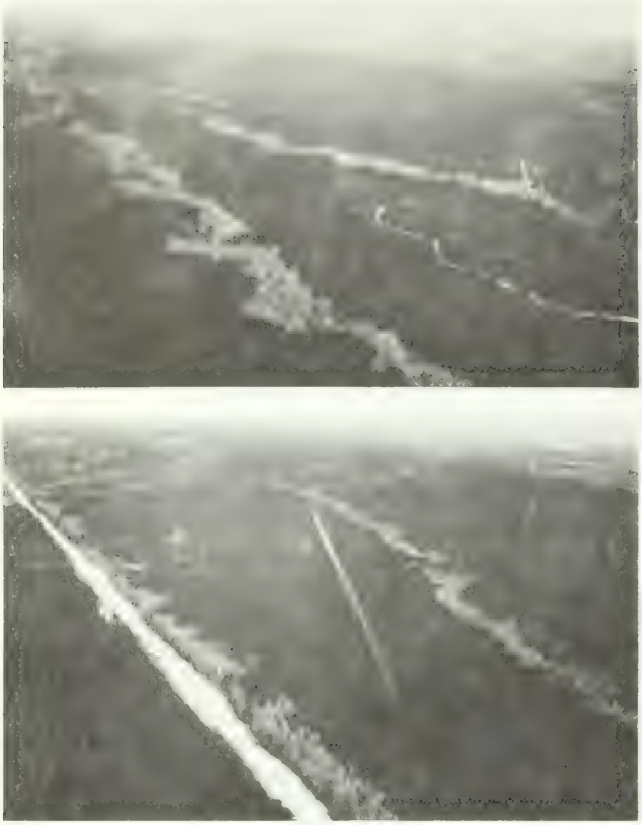

Figure 28.—*Unburned narrow, isolated crown strips showing smooth and ragged edge (foreground). Broad, grouped strips can also be seen (background) (top). Unburned tree crown strip with inward curve (bottom).*

movement. This would be consistent with a downward moving stream of air carrying embers from the main fire and igniting a secondary fire that spread in both directions, pushed by winds spreading outward from the air stream as it reached the ground. In one narrow strip, trees with scorch on opposite sides were only 2 feet apart. More typically, they were 5 to 10 feet apart. The line of opposing spread was generally located from one-fourth to one-third the width of the strip from the apparently more intense (smooth) side. In wide strips, there was often no charring along the center line; even needles a few inches above the ground were unscorched. These understory patterns were found along the entire length of all strips examined.

When the strip and understory pattern became disorganized, we invariably found that it had re-formed within a short distance and concluded that it had changed for one of two reasons:

1. A single strip had re-formed into two or more strips, or multiple strips had re-formed into single strips. This was always accompanied by a change in the overhead tree-crown pattern in conformance with ground evidence.

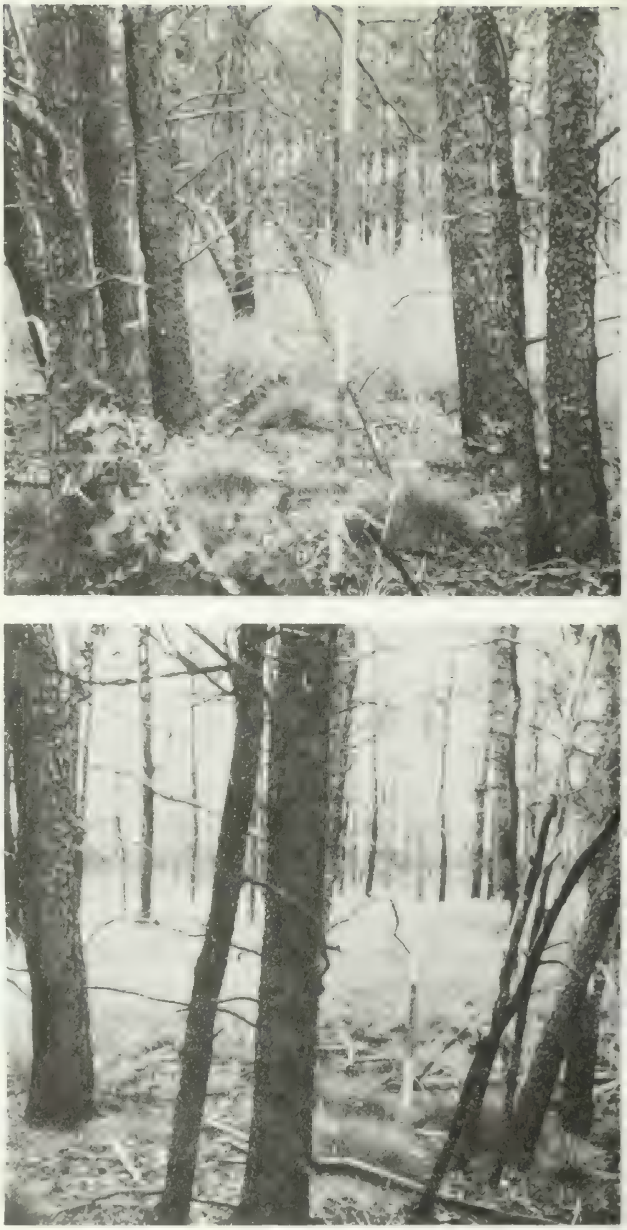

Figure 29.—*View of line of opposite spread in a unburned tree crown strip (looking in the directio of fire spread) (top). Note less charring visible o opposite side of tree stems than in bottom vie View of line of opposite spread in an unburned tre crown strip (looking in the direction from whic the fire is coming) (bottom). Note more charrin visible on opposite side of tree stems than in to view.*

2. The strip stopped 200 to 300 feet upwind of a intersecting road. We usually found the re-forme strip and understory pattern 50 to 80 feet on th other side of the road.

In one instance, a strip moved from conifers to hardwoods. Even though there was no crowning in the latter, the uncharred center line continued along a sidehill 200 feet long, with a 25° slope, about 150 feet from the bottom. The pattern indicated that along the length of this hill, the fire burned downslope below the strip and upslope above the strip. In another instance, when a strip crossed a small depression 20 feet deep by 100 feet across, the ground surface pattern was "lost" in the depression, but "found" again on the other side.

We examined the unburned crown strip that formed along the tractor/plow line where the fatality occurred. The edge was smooth on the fire side and ragged on the opposite side (fig. 22). The center line was offset about ⅓ of the distance from the fire side of the strip. The strip extended 1,000 feet beyond the point where the control line was abandoned and curved inward toward the fire. These features indicate that this strip was formed by the same process as the others. In this strip, we found a 2- to 3-foot-wide irregular line of unburned material resulting from the tanker spray pattern. This unburned line was 20 to 30 feet outside the unburned center line of the strip.

On the 1977 Bass River Fire in New Jersey, an abandoned vehicle, near which four firefighters were trapped, was on the southwest side of an unburned tree crown strip (fig. 30). The main fire was spreading southeastward and the strip was along the southwestern flank of the fire. Although in documenting the fire, Brotak (1976) concentrates on "blowup" conditions, his description of specific conditions associated with the fatality are identical to those of Mack Lake. He states:

> ...it appears as if the wind shifted from the northwest to the northeast during a part of the fire's run. This is believed to be responsible for trapping the men...this would have turned the flank of the fire to the north of the truck into a head fire quickly spreading to the southwest.

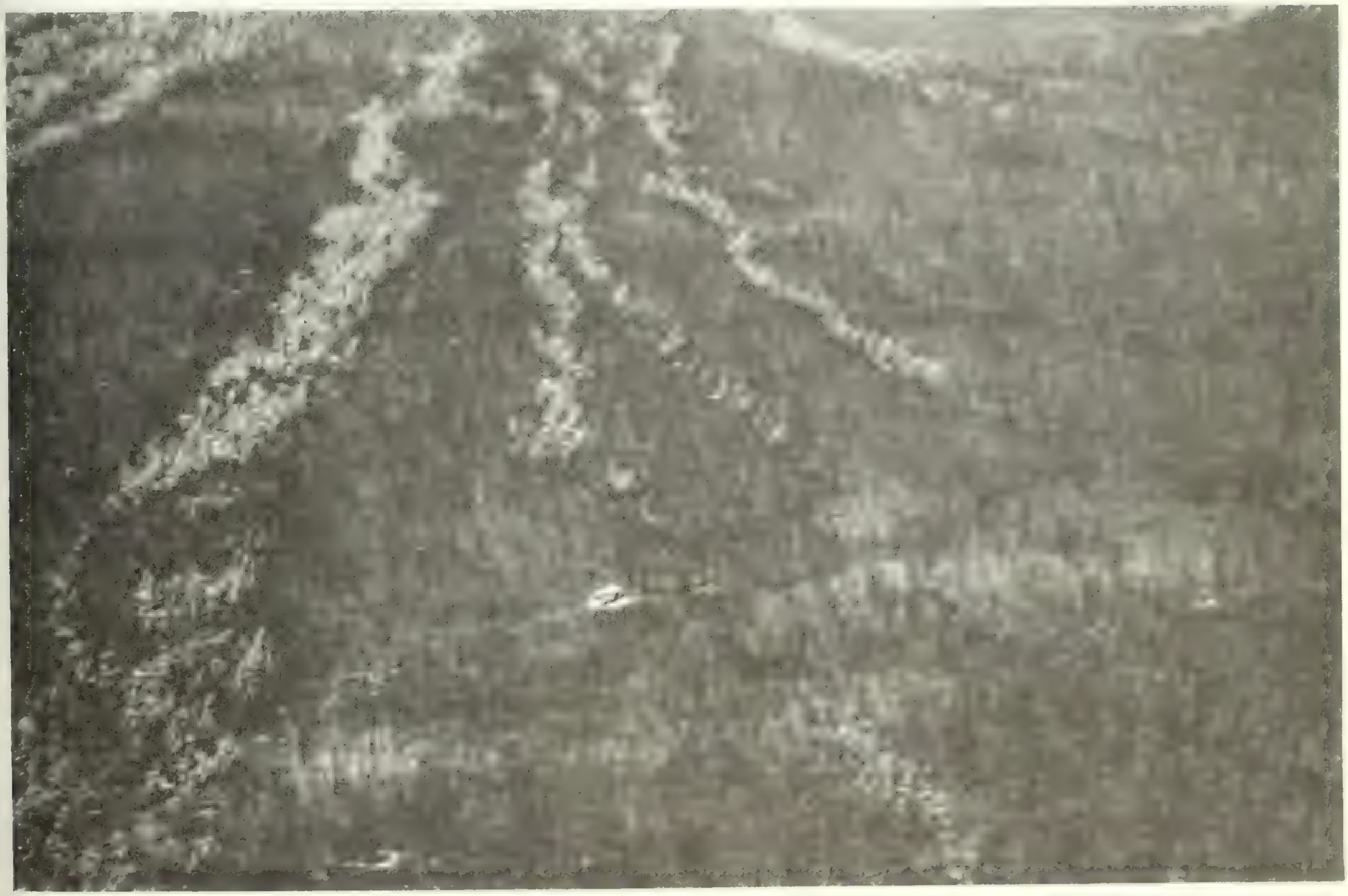

Figure 30.—*Aerial view of part of 1977 Bass River Fire in New Jersey—looking northwest. Abandoned vehicle can be seen in center. Photo courtesy of New Jersey Department of Environmental Protection.*

Figure 30 clearly indicates that the 90° wind shift must have been localized, because the pattern of unburned tree crowns does not change before or after the reported shift. Thus, the evidence, although not conclusive, points toward horizontal roll vortices as the cause of the four men being trapped on the Bass River Fire.

The upper-left photograph on the back cover is a view of the southwest flank of the Mack Lake Fire, looking north along Forest Service Road 4457 (just north of 4461). Although the fire was spreading southeastward at the time that the photograph was taken, the flames are clearly tilting toward the southwest—an identical situation to that described by Brotak (1976). This would be consistent with flames being driven by the outdraft of a horizontal roll vortex along the flank.

Haines (1982) compiled information from a dozen fires across the United States, Canada, and Australia, in fuel types ranging from sawgrass to mature timber, where unburned strips of fuels were reported. Several fires (Fletcher Road in Michigan, Bomb Range in North Carolina, and Bass River in New Jersey) revealed not only unburned crown strips similar to those at Mack Lake but also concentric ellipsoidal bands around the entire fire perimeter in the early stages. Haines (1982) also demonstrated that the existence of horizontal roll vortices in conjunction with crown fires is consistent with existing theories of heat transfer and fluid dynamics.

Additional research is needed to confirm or refute the hypotheses stated here. Several questions must be answered.

- How does a vortex form?
- What combinations of wind, fire size, and intensity result in horizontal roll vortices?
- What combinations of wind, fire size, and intensity permit patterns to curve around the head of a fire?
- Is there a maximum topographic irregularity above which a horizontal roll vortex will not form?
- Do multiple adjoining vortices form as they do in the atmosphere, or is this a single vortex phenomenon?
- Is the mechanism that forms a single large vortex the same as that which forms bands in conifer crown fires or bands in grass fires?

Necessary field observations include:

- Photographic documentation of horizontal roll vortices, including ground reference for scaling.
- Aerial photographs of burned areas before scorched foliage drops to the ground.
- Observations and documentation of the line of op posite spread in crown strips, particularly alon the forward perimeter of a fire.
- Meteorological and topographic features relate to the fire.

FIRE EFFECTS

The Mack Lake Fire took a heavy toll. One fir fighter lost his life. Losses from the destruction private property will probably exceed 2 million do lars when all claims are settled. Timber losses wer estimated at 2 million dollars and watershed an recreation losses at $166,000. On the positive sid range and wildlife values increased by $125,000.[9]

Site Effects

The depth of burn was very shallow (¼ to ½ inch In all areas except under the slash piles, ½ to 1 inc of duff remained after the fire. Due to the excellen insulating properties of duff, it is unlikely that an significant temperature increase occurred in the soi Therefore, soil micro-organisms were likely not sig nificantly affected by the fire. The remaining duf coupled with essentially flat topography, should e fectively prevent soil erosion, and the only effect o the soil should be an increase in nutrients for 2 t 3 years.

One season after the fire, the hardwood specie (primarily oak and aspen) had resprouted vigorousl indicating little root damage. In the first year, aspe sprouts were 2 to 7 feet high and oak sprouts ofte equaled the height of the plants prior to the fire (to 4 feet). Thus, wherever understory oak was pres ent in the jack pine stands, the fire acted as a re leasing agent. Similarly, most of the herbs and wood shrubs present prior to the fire had resprouted vig orously. Finally, the usual assortment of pioneer spe cies, such as fireweed (*Erechtites hieracifolia*) an pin cherry (*Prunus pensylvanica*), were relativel abundant. In general, plant cover was quickly re established on virtually all of the burned area. Ad ditional research is currently underway to documen the response of the plant communities to the fire.

In the hardwood stands, effects on the overstor ranged from 100 percent mortality adjacent to area where the fire was crowning in jack pine to virtuall no effect where the fire gradually died out durin the night. Many of the trees that were top-kille have resprouted. Consequently, the new stand wi likely contain a high percentage of coppice growth

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[9] *Data obtained from the Mack Lake Individua Forest Fire Report, Form 5100-29.*

Jack Pine Reproduction

One week after the fire, 10 seed count samples were taken in the burned area. Seeds were found on nine plots and the exception had no trees of seed-bearing age within a reasonable distance. On the nine plots with seeds, the counts averaged 300,000/acre, with a range of 90,000 to 1,000,000. Riley (1975) states that 20,000 viable seeds per acre are necessary for adequate stocking. Data summarized by McRae (1979) indicate that jack pine seed viability averages 50 percent. Thus, 40,000 seeds/acre should provide adequate stocking. Wherever seeds fell following the fire, the number appears to be more than adequate to regenerate the stand. Chrosciewicz (1974) rates a postburn duff depth of less than 1 inch as high quality in terms of seedling survival. Because most of the fire area fits this class, there is every reason to expect good reproduction wherever a seed source is available.

Because initial conditions for reproduction were ideal, the primary limiting factor is postburn rainfall. Five rain gauges were located across the burned area and rainfall data obtained for the growing season (May to September). Rainfall for the 5-month period averaged 16.3 inches (normal = 14.4 inches), with a range of 15.1 to 17.8 inches between the five rain gauges. Thus, all areas of the fire received between 5 and 19 percent above average rainfall for the first growing season. Only 1 month (August) was significantly below average (-2.2 inches), but even then, no more than 2 weeks elapsed between significant precipitation. Therefore, immediate postfire conditions were favorable for survival of jack pine seedlings.

Casual observation at the end of the first growing season indicated that optimistic expectations might be realized and that a dense stand of jack pine seedlings was likely to become established over much of the burned area. Three plots had an average of 9,000 seedlings/acre, with a range of 2,000 to 17,000. On the assumption that reforestation will occur, the Mack Lake Fire may have created what in 10 years will be 10,000 to 15,000 acres of prime habitat for the endangered Kirtland's warbler.

CONCLUSIONS

1. The Mack Lake Fire was not unique. Five other fires in excess of 10,000 acres have occurred in the Mack Lake area since 1820. The average interval between major jack pine crown fires is 28 years. Large crown fires will continue to be an intermittent fact of life in jack pine forests.
2. In northern Lower Michigan, the spring fire season appears to be typified by wide fluctuations in fire danger. Ninety percent of the days are either low or high, with less than 10 percent in between. Periods of moderate fire weather appropriate for prescribed burning rarely last more than 1 day. This complicates the prescribed burning planning process.
3. The Mack Lake Fire occurred just 6 days after ½ inch of rain fell. Only a slight precipitation deficit was recorded during the 4 months preceding the fire. It is clear that drought is not necessary for a major spring crown fire in jack pine. During the last 4 days of the drying period, relative humidity at 1300 ranged from 19 to 28 percent.
4. Horizontal roll vortices may be a common mechanism of lateral crown fire spread. If they form, they are a safety hazard for crews working on the flanks of crown fires. Further research into this phenomenon will be needed before the processes involved are understood and procedures for predicting the occurrence of horizontal roll vortices can be developed.
5. There are many large, relatively flat areas where jack pine predominates. Once a crown fire begins to run in this timber type, large-scale fire suppression efforts are needed. Fuel breaks, composed of less flammable hardwood species or widely spaced trees, could yield important fire suppression benefits such as reducing rate of spread and intensity, increasing firefighter safety, and providing an opportunity to make a stand.
6. The moisture content of old jack pine foliage is at a minimum during the onset of new growth in the spring. This increases crowning potential and may result in crown fire spread rates twice those encountered in the fall. These changes should be incorporated into fire management planning.
7. Several conditions contributed to the escape of the prescribed fire:
    - Spotting from slash piles.
    - Irregular groups of uncut trees adjacent to the prescribed fire area.
    - Locating the control line near the top of a 25-percent slope.
    - High windspeed (15-plus mi/h).
    - Low relative humidity (21 percent).
    - Low fine-fuel moisture (7 percent).
8. The transition from prescribed burning to wildfire control is critical. Subsequent spot fires can threaten initial attack crews. Since confusion is possible when an escape is attacked, it is important that the transition be planned in advance.

9. In jack pine, a fire can develop from an initial spot to a running crown fire in as little as 10 minutes and to project size in 20 minutes. This requires a rapid change in perspective by fire management personnel at all levels. Firefighters may have to shift from building line to escaping; dispatchers from moving crews to ordering overhead teams and fire camps; and the fire boss from control to community evacuation. Every member of an organization must immediately recognize the changed situation and take appropriate action.
10. The average rate of spread of the Mack Lake Fire (2 mi/h) was similar to that of other fast-moving crown fires. The maximum rate of spread (6 to 8 mi/h) equals the fastest recorded rate for which we had data.
11. During the fire's major run, average fireline intensity (8,800 Btu/ft/sec) was similar to that for other major crown fires. The 1-hour maximum fireline intensity (15,500 Btu/ft/sec) was less than that for three major fires for which we had data. The 15-minute peak intensity (29,500 Btu/ft/sec) may have approximated an upper limit for moving crown fires.
12. The number of permanent and seasonal residences in and adjacent to wild land areas is increasing. Noting that two out of three homes in Mack Lake did not burn, an expanded program should be developed to explain to homeowners the potential for wildfire damage and how to locate and landscape their homes to prevent loss.

Fire is an important and in some cases essential land management tool. It can also be terribly unforgiving of human error. Considerable skill and knowledge is required to successfully walk what is often a narrow, winding path between accomplishing land management objectives and reducing the risk of adverse consequences. A potentially explosive fuel type such as jack pine only serves to exacerbate the situation.

Fire is, however, controlled by fixed physical laws. Careful analysis generally reveals that what often appears as erratic behavior is related to known (though often incompletely understood) physical processes. We hope that this analysis has contributed to an increased understanding of these processes. It is important that we not only learn from experience, but that we also maintain a public and private awareness of fire's potential in jack pine so that we can avoid a repetition of the Mack Lake Fire of 1980.

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APPENDIX I. MEASURING THE FIRE

Fire Geometry

For the spot fire west of Highway 33, perimete and area were scaled from a map. The final area wa also scaled from a map and the final perimeter wa obtained from the fire analysis report (USDA Fores Service 1980). For intermediate areas, the perimete and area were calculated by assuming an elliptica shape with the major axis equal to the distance between the fire's forward position and the rear of th fire. The minor axis was equated with the estimate width of the fire at each observation. Before the win shift, the length of head was assumed to equal th minor axis. After the wind shift, the head length wa estimated from a map. Greater precision in calculating perimeter and length of head was not warranted, given the available data. Because this procedure does not incorporate irregularities, i underestimates the actual perimeter.

We estimate that at 1325 the fire was 4 miles lon and 1.5 miles wide, yielding a length to width rati of 2.7:1. Equations developed by Anderson (in press predict a 5.4:1 ratio with a 15 mi/h mid-flame win speed. Wind direction variability (not incorporate in Anderson's model) would decrease the forward:flank spread ratio. Horizontal roll vortices woul increase observed lateral spread beyond what woul normally be expected (thereby further decreasing th ratio). A simpler model developed by Simard an Young (1978) predicts a 1.9:1 ratio under the sam conditions.

Rate of Spread

Rate of spread was determined by dividing th distance traveled between successive reports of th fire's forward position by the time interval betwee the reports. Some reports were obtained from th district log book and some were based on estimate made by observers.

Fireline Intensity

Byram (1959) gives a formula for fireline intensity

$$I = hwr$$ (1

where I = fireline intensity (Btu/ft/sec),
h = heat value of the fuel (Btu/lb),
w = weight of fuel consumed (lbs/ft^2), an
r = rate of spread (ft/sec).

In using (1) we assumed that all of the fuel was consumed in the flaming front. Although this overestimates intensity to some extent, there is no reliable method for separating fuel consumed by the fire front from that consumed afterward. We felt that for the Mack Lake Fire, the resulting error would be relatively small.

Energy Release

The total energy released by the fire front per unit of time is:

$$E_f = I_f L_f \tag{2}$$

where E_f = frontal energy release rate (Btu/sec),
I_f = fireline intensity at the front (Btu/ft/sec), and
L_f = length of the fire front (ft).

Although the fire front is generally less than one-fourth of the total perimeter, most of the fire's energy will be released at the front due to its high fireline intensity relative to the remainder of the perimeter.

The total energy released by the fire can be determined by:

$$E_t = 43{,}560\ hwa \tag{3}$$

where E_t = total energy released by the fire (Btu) and
a = fire area (acres).

Dividing E_t by the time interval over which it is measured yields the total energy release rate per unit time.

Residence Time

The length of time that a fuel particle will continue to burn was given by Anderson (1969):

$$T_r = 8d \tag{4}$$

where T_r = flaming residence time (minutes), and
d = fuel particle diameter (inches).

For the Mack Lake Fire, little woody material in excess of ¼ inch was consumed. Thus, typical residence time was 2 minutes.

Heat Value

Hough (1969) gives low heat of combustion values of various components of jack pine and aspen fuel complexes (table 8). These were adjusted for heat losses due to vaporization of fuel moisture. Weighted average heat of combustion for jack pine (7,900 Btu/lb) and hardwood (7,370 Btu/lb) fuel complexes were obtained. The dense, black smoke emitted by the Mack Lake Fire (front and back cover photos) indicates incomplete combustion, as is typical of large fires. Therefore, using data from Byram (1959), an incomplete combustion heat value reduction was estimated for jack pine surface fuels (12 percent) and foliage (28 percent). The weighted average reduction (14 percent) gave a heat of combustion of 6,820 Btu/lb for the jack pine fuel complex. For aspen, with a less intense surface fire, a reduction of 6 percent yielded a value of 6,930 Btu/lb of fuel. Finally, an average radiation loss of 800 Btu/lb (Byram 1959) gives a heat yield (h) of approximately 6,000 Btu/lb for jack pine and 6,100 Btu/lb for the hardwood fuel complex. The latter values were used for all intensity calculations.

Table 8.—*Heat of combustion value of fuels consumed by the Mack Lake Fire*

	Low heat value	Average moisture content[2]	Heat loss to vaporization	Fuel consumed[3]	Weighted average heat value
	Btu/lb[1]	*Percent*		*Percent*	*Btu/lb*
Jack pine needles	8,575	120	1,165	0.28	
Jack pine twigs	8,707	15	145	.13	
Jack pine litter[4]	8,657	10	97	.24	
Jack pine duff	7,857	25	242	.35	7,908
				1.00	
Aspen, oak litter	7,952	10	97	.30[4]	
Aspen duff[5]	7,280	25	242	.61	
Aspen twigs	8,150	15	145	.09	7,371
				1.00	

[1] Data from Hough (1969). Corrected for ash content and vaporizing water of reaction.
[2] Estimated average for all material consumed.
[3] From tables 4 and 5.
[4] Includes shrubs and herbs.
[5] Estimate based on average increase in ash content for other species.

Fuel Consumption

We distinguished four fuel consumption rates. In the prescribed burn area (1024-1206) fuel consumption was 26 tons/acre ($w = 1.2$ lbs/ft^2). Between 1206 and 1222 the fire burned on the ground in a jack pine stand. From table 4a, fuel consumption without crown foliage was 7.3 tons/acre ($w = 0.34$ lbs/ft^2). Between 1222 and 1825, 20,000 acres were burned. We assumed that all the non-hardwood stands (17,720 acres—table 3) were burned during this period. Thus, 2,280 acres of hardwood were also burned during the same period. Based on that assumption and data from table 3, the weighted average fuel consumption between 1222 and 1825 was 10.5 tons/acre ($w = 0.48$ lbs/ft^2). We assumed that the fire burned only in hardwood stands after 1825 consuming 14.6 tons/acre ($w = 0.67$ lbs/ft^2).

Energy Balance

Byram (1959) gives equations for comparing the energy flow rate of the wind with the rate at which thermal energy is converted to kinetic energy. For a neutrally stable atmosphere:

$$P_w = \frac{\rho\,(v-r)^3}{2g} \qquad (5)$$

where P_w = the rate of flow of kinetic energy in the wind field at height z above the fire (ft-lb/sec/ft^2),
ρ = air density at height z (lb/ft^3),
v = windspeed at height z (ft/sec),
r = forward rate of spread of the fire (ft/sec), and
g = acceleration of gravity (ft/sec^2).

$$P_f = \frac{I}{C_p\,(T_o + 459)} \qquad (6)$$

where P_f = the rate at which thermal energy is converted to kinetic energy in the convection column of a fire (ft-lb/sec/ft^2),
I = fireline intensity (Btu/sec/ft),
C_p = specific heat of air at constant pressure (Btu/lb/°F), and
T_o = air temperature at the surface (°F).

The following values were used to calculate P_w and P_f in table 7.

Altitude (ft)	ρ	v	
surface	0.0765	13	r – table 6a
1,000	.0743	20	g = 32
2,000	.0721	51	I – table 6b
3,000	.0706	53	C_p = 0.24
4,000	.0679	44	T_o = 80

APPENDIX II. COMPARING FIRE-DANGE RATING SYSTEMS

Fire danger can be defined as an assessment the expected occurrence, rate of spread, and intensi of wildland fires resulting from an observed state the weather, fuels, and topography. The transfc mation from a weather observation to expected fi behavior is strongly dependent on microclimate a fuel characteristics. Thus, to evaluate the worst fi danger, the National Fire-Danger Rating Syste (NFDRS) estimates the moisture content of roun wood, without bark, off the ground, and in the op (Deeming *et al.* 1977). In contrast, to evaluate a erage fire danger, the Canadian Fire Weather Ind (FWI) estimates the moisture content of surface l ter and duff under a canopy (Van Wagner 1974b). is instructive to compare how the two contrasti systems portrayed fire danger during the 1980 sprii season at Mack Lake.

FWI class boundaries were established on the sar basis as the NFDRS Burning Index (BI), using c matological data from Gore Bay, Ontario, the close comparable Canadian station (Simard and Vale zuela 1972). FWI values were calculated using M weather data for April and May 1980 (table 9, f 31). We normalized the two data sets by dividing ea FWI and BI value by the maximum value, there permitting a direct comparison of the two indices (f 32). The FWI indicates similarities to the BI in th the times of peak fire danger are the same. The FV also suggests that the fire season was bimodal, b the relative percentages are different (fig. 33). On 9 days (25 percent) were high to extreme, 23 da (64 percent) were low, and 4 days (11 percent) we moderate. There were four occasions when the ind jumped from low to high (or vice versa) in a sing day.

There is a difference in the response of the t systems immediately after a rainfall of 0.1 inch more. On three out of six occasions[10], 1 day aft significant rain, the BI jumped to the high class (t ble 1, fig. 2). It remained at zero only once. In cc trast, the FWI remained at zero 1 day after signi cant rain on four of the six occasions and did not ri higher than the moderate class on the remaini two. The lag in the FWI eliminated three appare lesser fire danger peaks implied by the BI. The FV indicates that most of the fire season had had lo fire danger, except for four distinct peaks.

---

[10] *Omitting two occasions when more than 0.1 in of rain was recorded on the subsequent day.*

Table 9.—*National Fire-Danger Rating System (NFDRS), Burning Index (BI), and Canadian Fire Weather Index (FWI) values for April and early May 1980 at Mio, Michigan*

	NFDRS	BI		FWI
Date	(BI)[1]	BImax	FWI	FWImax
April 1	62	0.69	7	0.17
2	70	.78	12	.29
3	54	.60	16	.39
4	0	.00	0	.00
5	44	.49	1	.02
6	47	.52	2	.05
7	37	.41	2	.05
8	0	.00	0	.00
9	0	.00	0	.00
10	0	.00	0	.00
11	10	.11	0	.00
12	0	.00	0	.00
13	31	.34	0	.00
14	0	.00	0	.00
15	0	.00	0	.00
16	52	.58	0	.00
17	40	.44	1	.02
18	58	.64	5	.12
19	80	.89	14	.34
20	46	.51	1	.02
21	49	.54	7	.17
22	54	.60	11	.27
23	90	1.00	19	.46
24	73	.81	10	.24
25	58	.64	2	.05
26	0	.00	2	.05
27	0	.00	2	.05
28	0	.00	1	.02
29	0	.00	0	.00
30	0	.00	0	.00
May 1	10	.11	0	.00
2	32	.36	1	.02
3	53	.59	14	.34
4	63	.70	25	.61
5	79	.88	41	1.00
6	2	.02	8	.20

[1] Fuel model Q.

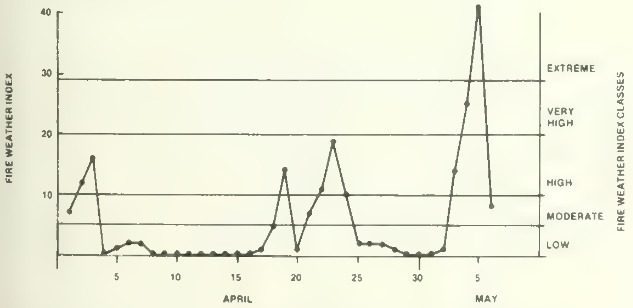

Figure 31.—*Canadian Forest Fire Weather Index (FWI) for Mio, Michigan, April and early May 1980.*

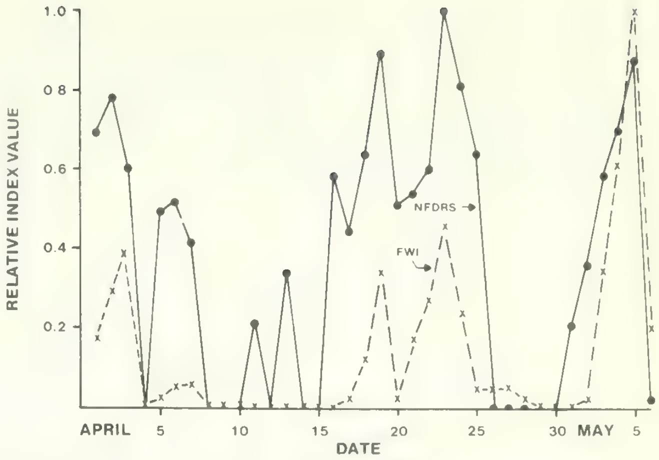

Figure 32.—*Relative values of the National Fire-Danger Rating System (NFDRS) Burning Index and the Canadian Fire Weather Index (FWI) for Mio, Michigan, April and early May 1980.*

Perhaps most important, the fire danger peaks indicated by the FWI are of different magnitudes. While the first three peaks were similar and in the high range, the fourth (on the day of the Mack Lake Fire) was well into the extreme range—more than twice as high as the next highest peak. Thus, the FWI implied that fire danger on May 5 was considerably more severe than it had been during the previous three peaks.

Each system reflects the aspect of fire danger it was designed to measure. Because it predicts fire danger in the open, the NFDRS reaches peak values quickly and remains relatively high under continued drying. In so doing, however, the system may lose some ability to distinguish between varying degrees of high to extreme danger under a closed forest canopy. Because the FWI predicts fire danger under a

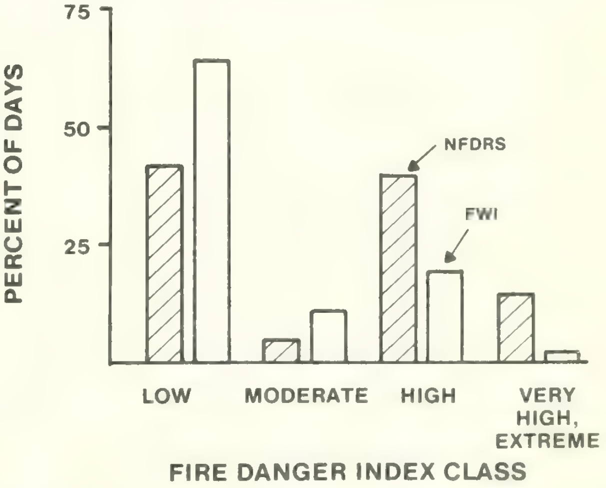

Figure 33.—*Percent of days by fire-danger rating index class.*

canopy, it responds more slowly than the NFDRS and may, therefore, be better able to distinguish fire danger peaks in forest stands. Assuming that fire managers would respond differently to two portrayals of the same fire season is sufficient justification for further study of these differences.

ACKNOWLEDGMENTS

A major case study involves contributions from many persons other than the authors. Because we arrived at the fire site after the advance had stopped, we depended on information and assistance generously and unhesitatingly provided by many persons who had witnessed or were involved in events: Harvey Gibson and Jack Godden, Region 9 Fire and Aviation Management; Clifford Reedy and Horace LaBumbard, Huron-Manistee National Forest; Vendel Bosman, Tom Bates, Mike Harnois, Tom Hahn, Dick Lord, and Tom Striker, Mio Ranger District; Don Grant, Ron Wilson, and Gerry Grieve, Michigan Department of National Resources; and Ed Falkowski, National Weather Service. We would also like to thank Hal Anderson, Northern Forest Fire Laboratory, Dale Wade, Southern Forest Fire Laboratory, and Darold Ward, Pacific Northwest Forest and Range Experiment Station, for their numerous helpful comments and suggestions.

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er Right Photo.—*As with many natural processes, a fully developed crown fire dwarfs suppression efforts.
hoto courtesy of the Huron-Manistee National Forest, Mio Ranger District.*

er Left Photo.—*Looking north along the southwest flank of the fire. Although the fire is spreading south-
astward (left to right), the flames are being driven to the southwest (right to left). The action of a horizontal
oll vortex could account for this apparent anomaly. Photo courtesy of the Huron-Manistee National Forest,
io Ranger District.*

om Photo.—*The Mack Lake Fire as it burned through the Kirtland Warbler Management Area, shortly
fter passing through the village of Mack Lake. Photo courtesy of the Huron-Manistee National Forest, Mio
anger District.*

Simard, Albert J.; Haines, Donald A.; Blank, Richard W.; Frost, John S. The Mack Lake Fire. Gen. Tech. Rep. NC-83. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1983. 36 p.

Describes the Mack Lake Fire near Mio, Michigan. Few documented wildfires have exceeded its average spread rate (2 mi/h) and energy release rate (8,800 Btu/ft/sec). The extreme behavior resulted from high winds, low humidity, low fuel moisture, and jack pine fuels. Horizontal roll vortices may have contributed to the death of one firefighter.

KEY WORDS: fire behavior, crown fires, jack pine, weather, fuels, horizontal roll vortices.

United States Department of Agriculture

Forest Service

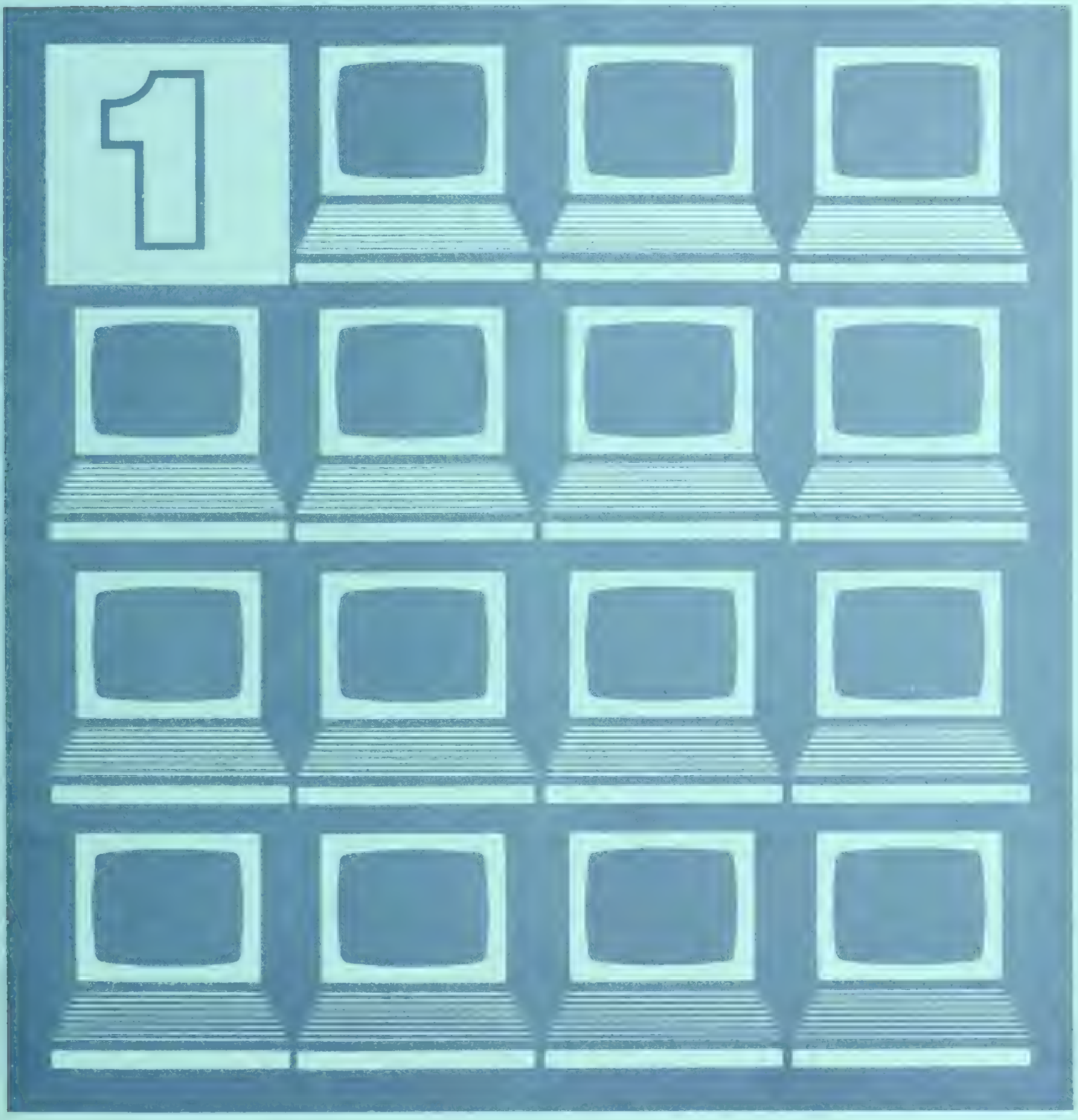
North Central Forest Experiment Station

General Technical Report **NC-84**

The Microcomputer Scientific Software Series 1

The Numerical Information Manipulation System

Harold M. Rauscher



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1983

PREFACE

The microcomputer scientific software series will present a continuing set of BASIC language, small computer oriented programs, unified by the same data interchange standard. Every program in this series will be input-output compatible with every other program in this series.

Updates, corrections, and changes to programs in this series will be forthcoming as necessary. Users are encouraged to submit extensions, useful changes, or identified errors to the author for inclusion in the next update. Originators will be given full credit for their contributions. It is only through diligent improvement of existing programs that truly outstanding software will eventually become a reality for small computers.

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HE MICROCOMPUTER SCIENTIFIC SOFTWARE SERIES 1:
IE NUMERICAL INFORMATION MANIPULATION SYSTEM

Harald M. Rauscher, *Research Forester,*
Marquette, Michigan

GENERAL INFORMATION

Identification

ystem Name: Numerical Information Manipulation System (NIMS)
ocation: North Central Forest Experiment Station
1831 Hwy. 169 E.
Grand Rapids, Minnesota 55744
anguage: BASIC
ystem: Radio Shack TRS-80 Microcomputer[1]

Summary

eneral

NIMS combines the versatility of a word process- ig system and the ability to manipulate mathe- iatical or statistical data in numeric matrix form. he system allows operations on single numbers, ntire rows or columns of numbers, or on entire data iatrices. Data elements may be transformed by log- rithmic, power, exponential, and other operations. hen data sets are treated as a single matrix, they ay be added, subtracted, multiplied, inverted, sep- ated, or merged.

ocumentation

This documentation will explain the operation of IMS, detail how the program functions in enough epth to allow a knowledgeable user to implement iprovements and extensions, and present the com- ete source code listings.

Objectives

(a) Provide small computer users with an efficient and flexible numeric data manipulation system.

(b) Provide users sufficient instructions to help them implement additional capabilities.

Goals

After reading this documentation, users will be able to:
(a) handle NIMS efficiently.
(b) Gain almost total automated control of their numeric data sets.

Assumptions

I assume that the users of NIMS are also programmers. Consequently, this documentation is aimed at those who understand the operating environment of their small computers, can program them in the resident BASIC dialect, and know some of the differences between the many BASIC dialects.

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[1] *Mention of trade names does not constitute en- orsement of the products by the USDA Forest Serv- e.*

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Quick Reference Guide

The functions performed by the data management system are:

1. Matrix alteration program
   (a) change any one element
   (b) delete a column
   (c) delete a row
   (d) add a column
   (e) add a row
   (f) add a row/column with a fixed value
   (g) set any portion of a row/column to a fixed value
   (h) merge any two matrices either by rows or by columns
   (i) extract any portion of a matrix as a new matrix
2. Add or subtract any two matrices
3. Multiply all elements of a matrix by a scalar
4. Multiply two matrices together
5. Transpose a matrix
6. Invert a matrix
7. Transform the elements of a matrix to
   (a) absolute values
   (b) integer values
   (c) exponential values
   (d) elements raised to a power
   (e) square roots
   (f) natural logarithms
   (g) base 10 logarithms
   (h) smooth variables by moving averages
8. Create a diagonal matrix
9. Perform row/column operations
   (a) interchange two rows
   (b) interchange two columns
   (c) multiply a row by a constant
   (d) multiply a column by a constant
   (e) add one row multiplied by a constant to another row
   (f) add one column multiplied by a constant to another column
   (g) divide a row/column by any element in the matrix by referring to its row/column identifier

APPLICATION

Introduction

This section of the guide explains how to use NIM
It presents each option in the system and then
lustrates it in a sample terminal session.

Operating Instructions

Once the computer system is under control of t
BASIC interpreter, the main program of NIMS
executed by typing <RUN> "MAIN/BAS". A me
of choices, numbered 1-16, appears on the video d
play and you are asked to make a selection (fig.
The first seven selections remain the same for
menus. Selection <1> returns you to the menu
the main program regardless of where you are in t
system. Selection <2> causes the NIMS system
relinquish control to the BASIC interpreter. Choic
3-7 read a matrix from disk, write a matrix to dis
allow keyboard entry to data, display a data matr
and print a data matrix to a lineprinter, respective
See documentation by Rauscher and Buhyoff (198
for further details.

The video display of matrix A(R,C) is a wind
that shows a block of data (13 rows by 4 colum
on the screen. By depressing the up, down, left,
right arrows on the keyboard, you select a porti
of the data matrix for display. Pressing the <.> k
activates a subroutine to change the names of t
variables of the data set. Pressing the <CLEA
key returns you to the menu section of the curre
program. After completion of the subroutines ac
vated by choices 3-7, the main menu is display
again.

Choice <8> executes the matrix alteration p
gram. The matrix alteration menu is displayed (
2) and you are asked to select from options 1-
Selections 1-7, as discussed above, remain the sar
Selection <8> causes the program to ask for the r
and column identification of the element to
changed. When a coordinate pair is entered,
<4,5>, the program displays the current value
the matrix element (row = 4, column = 5) a
prompts for the new value. When you provide
new value, the program displays the matrix on
video screen to confirm that the change had ind
been made. To preserve the change, you must sel
<4>, which activates the routine to save the d
on disk. WARNING! If you fail to save the curr
data set to disk when the program cautions you
do so, you may lose the data set.

FORESTRY SCIENCES LABORATORY, U.S. FOREST SERVICE
MENU FOR: NUMERICAL INFORMATION MANIPULATION SYSTEM

```
 1. RETURN TO MAIN MENU                2. GO TO BASIC
 3. READ A MATRIX FROM DISK            4. WRITE A MATRIX TO DISK
 5. ENTER A MATRIX MANUALLY            6. DISPLAY MATRIX ON VIDEO
 7. PRINT MATRIX                       8. ALTER MATRIX
 9. ADD/SUB TWO MATRICES              10. SCALAR/MATRIX OPERATIONS
11. MATRIX MULTIPLY                   12. TRANSPOSE A MATRIX
13. INVERSE A MATRIX                  14. TRANSFORM DATA
15. CREATE SPECIAL MATRICES           16. ROW/COL OPERATIONS
SELECT ONE OF THE ABOVE—>.
```

Figure 1.—*Menu of choices for program MAIN of NIMS.*

Option <9> deletes any column and <10> deletes any row in the data matrix. Option <11> adds one column to the end of the data matrix. A column may not be added between two other columns. Option <12> adds one row to the end of the matrix. A row may not be added between two other rows. Under options <11> and <12>, you must put in one element of the row/column at a time. Option <13> adds a row/column where all elements are the same value. Option <14> allows portions of any row or column to be set to a specific fixed value.

Selection <15> merges two matrices. Before entering this option, you must put the base matrix into memory by choosing option <3> or <5>. The (1,1) element of the base matrix will remain as the (1,1) element of the new matrix. You are prompted to enter the name of the second matrix, i.e., the one that will be moved next to the base matrix. The program then prompts you to select merging by rows or columns. The rows or columns of the second matrix are added to the rows or columns of the base matrix to form the new matrix. Zero elements are added where the dimensions of the two matrices do not match. The merging procedure will become clear with a little experimentation.

Selection <16> extracts a submatrix from the original matrix. Any block of contiguous data elements may be removed from any matrix by specifying the coordinates of the upper left hand corner and those of the lower right hand corner. Selection <1> returns you to the main menu.

Selection <9> from the main menu (fig. 1) executes the add/subtract routine for two matrices. Matrix addition and subtraction is defined only for matrices with the same dimensions. You are prompted

FORESTRY SCIENCES LABORATORY, U.S. FOREST SERVICE
MENU FOR: MATRIX ALTERATION ROUTINE

```
 1. RETURN TO MAIN MENU                2. GO TO BASIC
 3. READ A MATRIX FROM DISK            4. WRITE A MATRIX TO DISK
 5. ENTER A MATRIX MANUALLY            6. DISPLAY MATRIX ON VIDEO
 7. PRINT MATRIX                       8. CHANGE AN ELEMENT
 9. DELETE A COLUMN                   10. DELETE A ROW
11. ADD A COLUMN                      12. ADD A ROW
13. ADD FIXED VALUE ROW/COL           14. CHANGE R/C TO FIXED VAL
15. MERGE TWO MATRICES                16. SPLIT A MATRIX
SELECT ONE OF THE ABOVE—>.
```

Figure 2.—*Menu of choices for program ALTER of NIMS.*

to enter matrix B into the memory and then to enter matrix C. The next prompt requests a choice between operations B+C and B-C. When the pertinent calculations are completed, the main menu is once again displayed.

Option <10> allows all elements in a matrix to be multiplied by a scalar (fixed number) or it allows a scalar to be added to all elements. Elements can be divided by using the inverse of the scalar and subtracted by using its negative.

Option <11> activates the matrix multiplication routine (fig. 3) and option <8> from the matrix multiplication menu allows multiplication of two matrices. The order of matrix multiplication is B x A where B is entered first and A second. The two matrices must be conformable under multiplication. Option <1> returns control to the main menu.

Selection <12> (fig. 1) executes the matrix transposition subroutine. You are prompted to enter the matrix, the rows and columns are transposed, and control is returned to the main menu.

Option <13> leads to the matrix inversion menu (fig. 4). Option <8> activates the matrix inversion routine. This routine uses a Gauss-Jordan column elimination algorithm after Hornbeck (1975). Only nonsingular, square matrices may be inverted w
this algorithm. If the matrix is singular, an er
trap tells you of this fact and shifts program cont
to the matrix inversion menu. Otherwise, the mat
is inverted, the determinant is displayed, and cont
is returned to the matrix inversion menu. The m
trix inversion routine in this program uses sin
precision variables (6-digit accuracy), but this m
not be enough to accurately invert those matric
that approach singularity. No attempt has been ma
to deal with this problem of error analysis. Cauti
you should check the accuracy of the inversion
multiplying the original matrix by its inverse to s
how well the identity matrix is achieved.

Returning to the main menu (fig. 1), option <1
leads to the data transformation matrix (fig. 5). C
tions 8-14 are straightforward transformations
every element in the data matrix. Option <1> r
turns control to the main menu.

Option <15> (fig. 1) creates a diagonal matr
This saves time because only the diagonal elemen
of the matrix need to be explicitly entered. The o
diagonal zeroes are automatically assigned. Und
the same option, a matrix of fixed values may al
be quickly created. For a sparse data set, you m
want to create a matrix of zeroes and then chan
the elements that are nonzero.

```
         FORESTRY SCIENCES LABORATORY, U.S. FOREST
                          SERVICE
          MENU FOR: MATRIX MULTIPLICATION ROUTINE

 1. RETURN TO MAIN MENU               2. GO TO BASIC
 3. READ A MATRIX FROM DISK           4. WRITE A MATRIX TO DISK
 5. ENTER A MATRIX MANUALLY           6. DISPLAY MATRIX ON VIDEO
 7. PRINT MATRIX                      8. MATRIX MULTIPLY
SELECT ONE OF THE ABOVE—>.
```

Figure 3.—*Menu of choices for program MATMULT of NIMS.*

```
         FORESTRY SCIENCES LABORATORY, U.S. FOREST
                          SERVICE
             MENU FOR: MATRIX INVERSION ROUTINE

 1. RETURN TO MAIN MENU               2. GO TO BASIC
 3. READ A MATRIX FROM DISK           4. WRITE A MATRIX TO DISK
 5. ENTER A MATRIX MANUALLY           6. DISPLAY MATRIX ON VIDEO
 7. PRINT MATRIX                      8. MATRIX INVERSION
SELECT ONE OF THE ABOVE—>.
```

Figure 4.—*Menu of choices for program INVERSE of NIMS.*

```
        FORESTRY SCIENCES LABORATORY, U.S. FOREST
                        SERVICE
 MENU FOR: MATRIX DATA TRANSFORMATION ROUTINE

 1. RETURN TO MAIN MENU              2. GO TO BASIC
 3. READ A MATRIX FROM DISK          4. WRITE A MATRIX TO DISK
 5. ENTER A MATRIX MANUALLY          6. DISPLAY MATRIX ON VIDEO
 7. PRINT MATRIX                     8. ABSOLUTE VALUE
 9. INTEGER VALUE                   10. EXPONENTIATION
11. POWERS                          12. SQUARE ROOT
13. NATURAL LOGARITHM               14. BASE 10 LOGS
SELECT ONE OF THE ABOVE—>.
```

Figure 5.—*Menu of choices for program TRNSFORM of NIMS.*

```
        FORESTRY SCIENCES LABORATORY, U.S. FOREST
                        SERVICE
  MENU FOR: ELEMENTARY ROW/COLUMN OPERATIONS
                        ROUTINE

 1. RETURN TO MAIN MENU              2. GO TO BASIC
 3. READ A MATRIX FROM DISK          4. WRITE A MATRIX TO DISK
 5. ENTER A MATRIX MANUALLY          6. DISPLAY MATRIX ON VIDEO
 7. PRINT MATRIX                     8. FLIP TWO ROWS
 9. FLIP TWO COLUMNS                10. ROW x SCALAR
11. COLUMN x SCALAR                 12. ROW + SCALAR x ROW
13. COL + SCALAR x COL              14. (ROW OR COL) / ELEMENT
SELECT ONE OF THE ABOVE—>.
```

Figure 6.—*Menu of choices for program ELEMOPS of NIMS.*

Option <16> activates the elementary row/column operations menu (fig. 6). Elementary operations are carefully defined by the theory of linear algebra. A matrix that has been changed only through elementary operations is equivalent to its original form. The three allowable elementary operations are:

a. Interchange of rows/columns;
b. Multiplication of rows/columns by a scalar not equal to zero;
c. Addition of a row/column multiplied by a scalar to another row/column.

Options 8-13 (fig. 6) are self-explanatory. Option <14> simplifies the use of elementary operation b. You can make the leading element of a row equal to 1 by multiplying the entire row by the inverse of the first element in that row. This operation, equivalent to dividing the row by its leading element, is allowed in option <14> by specifying the row/column coordinates of the element.

Sample Terminal Session

This sample terminal session illustrates most of the operations discussed earlier.

```
                                      (Beginning)

           NORTHERN HARDWOODS LABORATORY, U.S. FOREST SERVICE        Execution begins

         MENU FOR:  DATA MANAGEMENT SYSTEM                           First Display on
                                                                       Video Screen
  1.  RETURN TO MAIN MENU                     2.  GOTO BASIC
  3.  READ A MATRIX FROM DISK                 4.  WRITE A MATRIX TO DISK
  5.  ENTER A MATRIX MANUALLY                 6.  DISPLAY A MATRIX ON VIDEO
  7.  PRINT MATRIX                            8.  ALTER MATRIX
  9.  ADD/SUB TWO MATRICES                   10.  SCALAR/MATRIX OPERATIONS
 11.  MATRIX MULTIPLY                        12.  TRANSPOSE A MATRIX
 13.  INVERSE OF A MATRIX                    14.  TRANSFORM DATA
 15.  CREATE SPECIAL MATRICES                16.  ROW/COL OPERATIONS

  SELECT ONE OF THE ABOVE--> 5.                                     Type input after an
                                                                      arrow or question
                                                                      mark prompt by the
                                                                      program.

 PLEASE ENTER:  NO. ROWS AND COLS (R,C).--> ? 2,3

 ENTER THE NAME FOR VARIABLE 1 --> ONE.....
 ENTER THE NAME FOR VARIABLE 2 --> TWO.....
 ENTER THE NAME FOR VARIABLE 3 --> THREE...                         Originate a matrix by
                                                                      selecting #5 and
                                                                      entering the example
                                                                      data set into its
                                                                      matrix structure.

 ROW 1
 PLEASE ENTER:  VALUE OF COLUMN 1 --> 13........
 PLEASE ENTER:  VALUE OF COLUMN 2 --> 67........
 PLEASE ENTER:  VALUE OF COLUMN 3 --> 1,34......
 ROW 2
 PLEASE ENTER:  VALUE OF COLUMN 1 --> 1005......
 PLEASE ENTER:  VALUE OF COLUMN 2 --> 43........
 PLEASE ENTER:  VALUE OF COLUMN 3 --> 92........
                                                                    After completing each ta
                                                                      you are returned to th
           NORTHERN HARDWOODS LABORATORY, U.S. FOREST SERVICE          command MENU for furth
                                                                      instructions.
         MENU FOR:  DATA SYSTEM MANAGEMENT

  1.  RETURN TO MAIN MENU                     2.  GOTO BASIC
  3.  READ A MATRIX FROM DISK                 4.  WRITE A MATRIX TO DISK
  5.  ENTER A MATRIX MANUALLY                 6.  DISPLAY A MATRIX ON VIDEO
  7.  PRINT MATRIX                            8.  ALTER MATRIX
  9.  ADD/SUB TWO MATRICES                   10.  SCALAR/MATRIX OPERATIONS
 11.  MATRIX MULTIPLY                        12.  TRANSPOSE A MATRIX
 13.  INVERSE OF A MATRIX                    14.  TRANSFORM DATA
 15.  CREATE SPECIAL MATRICES                16.  ROW/COL OPERATIONS
                                                                    To look at a data matrix
  SELECT ONE OF THE ABOVE --> 6.                                      select #6.
```

```
COL:     ONE          TWO          THREE
-----------------------------------------
R 1:     13           67           1.34
R 2:     1005         43           92
```

The example data set just entered

While inside option #6, depressing the period "." will allow changing variable names. Rows cannot be named.

```
WHICH COLUMN'S NAME WILL BE CHANGED? —> 2.
PLEASE ENTER NEW NAME —> VAR. 02.


COL:     ONE        VAR. 02        THREE
-----------------------------------------
R 1:     13           67           1.34
R 2:     1005         43           92
```

Data set names must be less than or equal to 7 letters.

Each data set must be saved to disk, selection #4, to preserve it. Caution: Failure to do this can mean loss of a data set.

```
ENTER FILENAME OF NEW DATA SET --> ? TEST

ENTER DISK DRIVE # WHERE DATA SHOULD BE SAVED —> ? 1_
```

Once the example set, now called "TEST", is saved to disk, you may retrieve it into active memory at any time through selection #3.

```
ENTER FILENAME OF DESIRED DATA SET —> ? TEST_
```

If a lineprinter is available, you may print TEST to obtain a paper copy.

```
PRESS <ENTER> WHEN PRINTER IS READY.?

PLEASE ENTER NAME OF DATA SET —> TEST.........
```

Lineprinter output.

```
                    TEST

COL:     ONE        VAR. 02        THREE
-----------------------------------------
R 1:     13           67           1.34
R 2:     1005         43           92
```

Selection #10 allows scalar/matrix operations. You may multiply by a scalar or add a scalar value to a data set.

```
ENTER (M)ULTIPLY OR (A)DD/SUBTRACT BY A SCALAR VALUE —> ? M_
```

You may subtract by adding a negative number.

```
ENTER VALUE OF SCALAR MULTIPLIER —> ? 100_

OPERATE ON A SINGLE (R)OW, (C)OLUMN OR (A)LL ELEMENTS —> ? C_
```

```
ENTER COLUMN NUMBER TO OPERATE ON --> ? 2_
```

```
COL:    ONE         VAR. 02      THREE
----------------------------------------
R 1:    13           6700         1.34
R 2:    1005         4300         92
```

Results of multiplying column #2 by 100.

```
COL:      1        2
--------------------------------
R 1:      13       1005
R 2:      6700     4300
R 3:      1.34     92
```

To transpose a matrix, select #12. This procedure will destroy the variable names previously assigned to the columns. Remember, to preserve this new matrix, you must write it to disk via selection #4.

```
THIS ROUTINE ADDS OR SUBTRACTS MATRICES.

PLEASE ENTER:  (A)DD MATRIX B+C OR (S)UBTRACT B-C --> A

ENTER MATRIX B FROM (1) DISK (2) KEYBOARD OR (3) ALREADY

IN MEMORY --> 3

PLEASE ENTER: C FROM 1=DISK, 2=KEYBOARD, 3=ALREADY LOADED? 3_
```

To add or subtract active matrices, choose selection #9.

```
COL:    ONE         VAR. 02      THREE
----------------------------------------
R 1:    26          134          2.68
R 2:    2010        86           184
```

Adding TEST to itself will double the values in the matrix.

Selection #8 erases the main program and executes a new one. On the new menu list, selections 1-7 have not changed.

```
         NORTHERN HARDWOODS LABORATORY, U.S. FOREST SERVICE

                MENU FOR:  MATRIX ALTERATION ROUTINE

  1.  RETURN TO MAIN MENU               2.  GOTO BASIC
  3.  READ A MATRIX FROM DISK           4.  WRITE A MATRIX TO DISK
  5.  ENTER A MATRIX MANUALLY           6.  DISPLAY MATRIX ON VIDEO
  7.  PRINT MATRIX                      8.  CHANGE AN ELEMENT
  9.  DELETE A COLUMN                  10.  DELETE A ROW
 11.  ADD A COLUMN                     12.  ADD A ROW
 13.  ADD FIXED VALUE ROW/COL          14.  CHANGE R/C TO FIXED VAL
 15.  MERGE TWO MATRICES               16.  SPLIT A MATRIX

  SELECT ONE OF THE ABOVE--> 8.
```

To change any one element, you must first enter the desired data set via selection #3 or #5 then selection #8 will change any single element.

```
LEASE ENTER:  LOCATION OF ELEMENT TO BE CHANGED (ROW, COL).? 1,3

ATRIX (R,C)= ( 1  , 3 )= 1.34

LEASE ENTER:  NEW VALUE OF ELEMENT.? -99.99_
```

```
OL:     ONE          VAR. 02       THREE
----------------------------------------
 1:     13             67         -99.99
 2:     1005           43           92
```

Notice the change in data set TEST. The number -99.99 is used to identify missing values.

Selection #9 deletes any column and #10 deletes any row.

```
LEASE ENTER:  COLUMN TO BE DELETED.? 2_
```

```
OL:     ONE          THREE
------------------------------
 1:     13           -99.99
 2:     1005          92
```

Column #2 removed from data set TEST.

Similarly, selections #11 and #12 add a column or row.

```
ATRIX HAS DIMENSIONS (R,C)=( 2  , 2 )

NTER THE NAME FOR VARIABLE  3  -->  VAR. 3..
LEASE ENTER: VALUE OF ROW  1  COLUMN 3 ? 50
LEASE ENTER: VALUE OF ROW  2  COLUMN 3 ? 30_
```

```
OL:     ONE          THREE        VAR. 3
-----------------------------------------
 1:     13          -99.99          50
 2:     1005         92             30
```

Result of column addition.

Selection #13 creates a new row or column with the same value.

```
DD A (1) ROW OR (2) COLUMN WITH FIXED VALUE? 2
HAT IS THE NEW VALUE? -1

NTER THE NAME FOR VARIABLE  4 —>  FOUR....
```

```
OL:     ONE          THREE        VAR. 3        FOUR
-----------------------------------------------------
 1:     13          -99.99          50           -1
 2:     1005         92             30           -1
```

Result of selection #13.

Selection #14 changes any sequence of row or column locations.

```
CHANGE PORTIONS OF A (1) ROW OR (2) COLUMN? 1
WHAT IS THE NEW VALUE? 0
WHICH ROW/COLUMN IS TO BE CHANGED?  1
BEGIN CHANGE AT LOCATION? 1
END CHANGE AT LOCATION? 3_
```

Save this matrix to disk by calling it "TEMP".

```
COL:     ONE          THREE         VAR. 3           FOUR
-----------------------------------------------------------
R 1:     0            0             0                -1
R 2:     1005         92            30               -1
```

Selection #15 merges two matrices. To merge TEMP with TEST, enter selection 15 with TEMP in memory as the core matrix and then load TEST when prompted.

```
THE CORE (A) MATRIX HAS DIMENSIONS —>  2 BY 4
THE SECOND (B) MATRIX HAS DIMENSIONS —>  2  BY 3

MERGE A WITH B BY (1) ROWS OR (2) COLUMNS —> ? 1_
```

The maximum row and column dimensions are used for the merged matrix, and zeroes are used to fill in the empty places (as in locations 3,4 and 4,4).

```
COL:     ONE          VAR. 02       THREE            FOUR
---------------------------------------------------------
R 1:     0            0             0                -1
R 2:     1005         92            30               -1
R 3:     13           67            1.34              0
R 4:     1005         43            92                0
```

Selection 16 allows a matrix to be split to create a new matrix. With the above merged matrix in memory, this procedure yields the results at bottom.

```
THE MATRIX IN MEMORY HAS  4  ROWS AND  4  COLUMNS.

ENTER THE ROW, COLUMN COORDINATES OF THE UPPER LEFT
CORNER OF THE NEW MATRIX (R,C) —> ? 2,2

ENTER THE ROW, COLUMN COORDINATES OF THE LOWER RIGHT
CORNER OF THE NEW MATRIX (R,C) —> ? 4,3_
```

Select #1 to return to the main menu and then #11 for matrix multiplication.

```
COL:     VAR. 02     THREE
----------------------------
R 1:       92        30
R 2:       67        1.34
R 3:       43        92
```

```
          NORTHERN HARDWOODS LABORATORY, U.S. FOREST SERVICE

              MENU FOR:  MATRIX MULTIPLICATION ROUTINE

 1.  RETURN TO MAIN MENU                    2.  GOTO BASIC
 3.  READ A MATRIX FROM DISK                4.  WRITE A MATRIX TO DISK
 5.  ENTER A MATRIX MANUALLY                6.  DISPLAY MATRIX ON VIDEO
 7.  PRINT MATRIX                           8.  MATRIX MULTIPLY

 SELECT ONE OF THE ABOVE-->  .
```

Enter data set TEST into memory and display it. Then select #8.

```
COL:       ONE       VAR. 02     THREE
---------------------------------------------
R 1:       13          67        1.34
R 2:       1005        43        92
```

```
THE ORDER OF MULTIPLICATION IS B * A .

MATRIX B IS ALREADY IN MEMORY.
```

Remember: data set A must be conformable under the laws of matrix multiplication.

```
ENTER A FROM (1) DISK (2) KEYBOARD OR (3) IN MEMORY -->
```

Then select #2 and enter the 3x1 matrix displayed below.

```
COL:       ONE
---------------------
R 1:        1
R 2:        1
R 3:        1
```

After the multiplication routine, display the matrix in memory, the results of the matrix multiplication operation.

```
COL:          1
---------------------
R 1:        81.34
R 2:        1140
```

Next, return to the main menu and select #13.

```
                 NORTHERN HARDWOODS LABORATORY, U.S. FOREST SERVICE

                        MENU FOR:  MATRIX INVERSION ROUTINE

  1.  RETURN TO MAIN MENU                  2.  GOTO BASIC
  3.  READ A MATRIX FROM DISK              4.  WRITE A MATRIX TO DISK
  5.  ENTER A MATRIX MANUALLY              6.  DISPLAY MATRIX ON VIDEO
  7.  PRINT MATRIX                         8.  MATRIX INVERSION

  SELECT ONE OF THE ABOVE--> .
```

Enter the following matrix into memory via #5 and select #8.

```
COL:       ONE       TWO          THREE
------------------------------------------
R 1:        2         1             1
R 2:        1         2             1
R 3:        1         1             2
```

If the matrix has a true inverse, the determinant will be displayed.

```
THE DETERMINANT = 4

PLEASE DEPRESS ANY KEY TO RETURN TO MENU.
```

The inverse of the matrix is in memory and may be displayed, printed, or saved to disk. Note that the column names are destroyed because they are no longer significant.

```
COL:        1         2          3
---------------------------------------
R 1:       .75      -.25       -.25
R 2:      -.25       .75       -.25
R 3:      -.25      -.25        .75
```

Next, return to the main menu and select #14.

```
              NORTHERN HARDWOODS LABORATORY, U.S. FOREST SERVICE

            MENU FOR:  ELEMENTARY ROW/COLUMN OPERATIONS ROUTINE

 1.  RETURN TO MAIN MENU                 2.  GOTO BASIC
 3.  READ A MATRIX FROM DISK             4.  WRITE A MATRIX TO DISK
 5.  ENTER A MATRIX MANUALLY             6.  DISPLAY MATRIX ON VIDEO
 7.  PRINT MATRIX                        8.  FLIP TWO ROWS
 9.  FLIP TWO COLUMNS                   10.  ROW * SCALAR
11.  COLUMN * SCALAR                    12.  ROW + SCALAR * ROW
13.  COL + SCALAR * COL                 14.  (ROW OR COL) / ELEMENT

 SELECT ONE OF THE ABOVE-->
```

Next, enter data set TEST into memory.

```
COL:       ONE          VAR. 02          THREE
------------------------------------------------------------------------
R 1:       13             67              1.34
R 2:       1005           43             92
```

This routine defines the three allowable matrix elementary operations to be performed. In addition, you may exchange rows and columns. Select #8.

```
PLEASE ENTER: ROWS TO BE INTERCHANGED (X,Y)? 1,2_
```

Display the new data set with rows one and two interchanged.

```
COL:       ONE          VAR. 02        THREE
------------------------------------------------------------------------
R 1:       1005           43            92
R 2:       13             67            1.34
```

Select #12 to add a constant times one row to another row. In the example, row #2 is multiplied by 2 and the result is added to row #1. The result is given below.

```
PLEASE ENTER:  R2 + K * R1   (R2,K,R1)? 1,2,2_




COL:       ONE          VAR. 02           THREE
-------------------------------------------------------------------
R 1:       1031           177             94.68
R 2:       13             67              1.34
```

Select #14. This routine divides any row or column by any element identified by its location coordinates.

```
DO YOU WISH TO OPERATE ON A ROW (R) OR A COLUMN (C)? C

PLEASE ENTER:  WHICH ROW/COL DO YOU WISH TO OPERATE ON? 2

GIVE COORDINATES OF ELEMENT THAT WILL BE THE DIVISOR

(I,J)? 2,2_



COL:       ONE        VAR. 02             THREE
------------------------------------------------------------
R 1:       1031       2.64179             94.68
R 2:       13         1                   1.34
```

```
                 NORTHERN HARDWOODS LABORATORY, U.S. FOREST SERVICE

                    MENU FOR:  MATRIX DATA TRANSFORMATION ROUTINE

  1.  RETURN TO MAIN MENU                  2.  GOTO BASIC
  3.  READ A MATRIX FROM DISK              4.  WRITE A MATRIX TO DISK
  5.  ENTER A MATRIX MANUALLY              6.  DISPLAY MATRIX ON VIDEO
  7.  PRINT MATRIX                         8.  ABSOLUTE VALUE
  9.  INTEGER VALUE                       10.  EXPONENTIATION
 11.  POWERS                              12.  SQUARE ROOT
 13.  NATURAL LOGARITHM                   14.  BASE 10 LOGS
      SMOOTH VARIABLES

  SELECT ONE OF THE ABOVE--> ..
```

Enter the data set TEST into memory and display it. Then select #13.

```
COL:       ONE        VAR. 02          THREE
-----------------------------------------------------------------
R 1:       13         67               1.34
R 2:       1005       43               92
```

Display the result. The natural logarithms of the original data set are now in memory. All other transformations work the same way.

```
COL:       ONE        VAR. 02          THREE
-----------------------------------------------
R 1:       2.56495    4.20469          .29267
R 2:       6.91274    3.7612           4.52179
```

Return to the main menu and select #16.

(END)

PROGRAMMING PROCEDURES

System Characteristics

NIMS is written in BASIC for the TRS-80 Model computer. Two mini-disk drives and a lineprinter re recommended for best results. These programs hould be easy to modify for any microcomputer sysem that uses the BASIC language.

Memory size determines the maximum dimenons of the data matrices with which the system can ork. The current matrix dimensions for each major program of NIMS running on the fully expanded, 48,000 byte TRS-80 Model I system are:

a. MAIN/BAS	150 rows by 20 columns
b. ALTER/BAS	250 rows by 20 columns
c. MATMULT/BAS	45 rows by 45 columns
d. INVERSE/BAS	50 rows by 50 columns
e. TRNSFORM/BAS	150 rows by 20 columns
f. ELEMOPS/BAS	150 rows by 20 columns

The dimension statement, which defines size limit of the data set, is always located in line number 40000. Reducing the number of rows in a matrix increases the number of columns that can be accommodated and vice versa.

Data File Structure

The numerical data of interest are built into a matrix, Aij, where i = number of observations and j = number of variables. Each data set has three data files automatically defined for it. If "TEST" is the name of an example data set, then the data files "TESTM," "TESTN," and "TESTL" will be automatically created or updated every time "TEST" is saved to disk. File "TESTM" contains the matrix Aij, file "TESTN" contains the row and column dimensions, and file "TESTL" contains the names of the variables, i.e., columns, of Aij.

Program Code Documentation

Introduction

The programs are coded in the Microsoft (TM) BASIC language for direct use with the Radio Shack (TM) Level II BASIC interpreter. Unlike many other languages, BASIC allows concatention of several logical statements in one physical line. Microsoft BASIC uses the colon, ":," as the logical statement delimiter. Because each physical line costs 5 bytes of memory and each unnecessary space, 1 byte, small computer BASIC programs are written in compressed code. They look impossible to decipher, especially for those who normally program in FORTRAN. To make matters worse, internal program documentation is reduced to a minimum in BASIC because these statements use previous memory. Because of these memory constraints and the ability to refer unambiguously to any physical line in the program, the code is presented in the Appendix in the normal, compressed fashion. Each section of code is explained by reference to physical linenumbers.

Several conventions have been defined for the routines in this system. First, matrix A(R,C) always carries the data that is moved to and from disk, displayed on the video screen, or printed to the lineprinter. User-developed routines may use any variable names in computations as long as the results of data matrix operations end up in matrix A(R,C) before control is given to the input/output routines. Second, all missing values must be coded -99.99 to distinguish then from zeroes. The only program that now deals directly with missing values is program TRNSFORM. In general, operations that merely manipulate the structure of the data matrix will not be adversely affected by missing values. But you should be cautious: those routines that perform arithmetic operations on data elements are likely to produc errors if missing data are present.

NIMS is a group of 6 separate programs: MAI ALTER, MATMULT, INVERSE, TRNSFORM, an ELEMOPS. Limited memory necessitates balancin program length with data matrix size because bot must reside in memory concurrently.

Program SEED (Appendix I)

The SEED program, lines 13-668, which is th core of all NIMS programs, is essentially the sam code that is documented elsewhere by Rauscher an Buhyoff (1981). SEED is composed of 7 standard su routines that control the input and output operatio of other programs. These routines contain most the TRS-80 specific statements. Users wishing to ada NIMS to a different computer system must replac these 7 routines with similar ones defined by th new system requirements.

Lines 13-34 define a formatted input routine. Th variable FL, set in the calling program, contains th formatting information. FL > 0 allows both numer and alpha digits to be input from the keyboard. Th number of digits allowed is defined by the absolut value of FL. When FL < 0, only numeric digits, th negative sign, and the period are acceptable input When the absolute value of FL = 1, the input accepted and processing continues without need f a carriage return. This is useful for rapidly acceptin single digit choices such as "Y" or "2". At all othe times, input will not be processed until a carriag return is entered from the keyboard. The string va iable IN$ returns the input accepted to the callin program for further processing. You can substitut any routine that uses these variables to accomplis the same function.

The variable P, line 15, is set equal to the locatio of the screen cursor character. This address is store in memory locations 16416 and 16417 (decimal) i the level II TRS-80 computer and must be change to conform to the requirements of another compute system. Lines 16-23 pertain to single digit input and lines 24-34 pertain to multiple digit inputs.

Lines 36-47 implement a menu selection routin described in detail by Rowlett (1980). The addres on the video screen where the blinking cursor is t appear must be passed to this subroutine from th main program in variable X. The number of item in the menu list must be passed in variable XO. O return to the calling program, X contains the ite number selected. Extensive use of the video screen standards specific to the TRS-80 makes this routine system dependent. It is used in NIMS only once—in program MAIN, line 10120—and could be replaced by a form of the input routine of lines 13-34.

The sequential data set disk-read routine is in lines 100-180 and the sequential data set write-to-disk routine is in lines 190-270. These two routines are system-specific. Before the write-to-disk routine is entered, the correct matrix of data, column names, and dimensions must be in the variables A(.,.), N$(.), R, and C, respectively. A substitute routine must be able to read and write from/to a disk the three files associated with each data set as discussed under "Data File Structure."

Routine input, lines 290-435, allows a user to enter a data set into the matrix structure from the keyboard. After specifying the data set dimensions, variables R and C, and the name of each column, variable N$(.), you enter the data elements one row at a time. This routine does not contain any particular system-dependent statements.

Routines video, lines 440-619, and lineprinter, lines 620-668, are essentially the same. The data matrix is displayed on the video screen or on a lineprinter. Before this routine is entered, the matrix must be in variable A(.,.) and the associated column names must be in N$(.) with the dimensions in R and C. Lines 510 and 623 act as an error trap to ensure that some matrix is in fact in memory. The video routine is designed for a screen of 16 rows by 64 columns. Such a screen allows 13 rows and 4 columns of the data set on display at any one time. Different row numbers and columns can be accommodated by changing the number 13 or 4 wherever it occurs between lines 440-619. These routines should be more or less universal.

Program MAIN (Appendix II)

The MAIN program gives you command control access to every other subprogram in NIMS. Line 10 reserves required string space, sets the dimensioning routine flag, TX, to ON = -1, and jumps to the menu routine, always located between lines 700-920. Subroutine 42000 accepts a string variable, T$, centers it, and prints it as the next line on the video screen. The routine in 40000 dimensions the data matrices required and initializes any variables that need it. Variable MV is used for missing values recognized as -99.99. The dimensioning routine may be accessed only once per execution because run-time redimensioning of data matrices is not permitted by most BASIC's. In line 750, TX is redefined as OFF = 1 and the menu is displayed. Keyboard input is accepted in line 900, and after an error trap, the appropriate subroutine is called in line 910. After return from each subroutine of MAIN, the central menu is once more displayed, line 920.

The addition and subtraction of matrices, scalar multiplication, matrix transposition, and creation of special matrices (menu options 9, 10, 12, & 15), respectively, are subroutines in program MAIN. Matrix alteration, multiplication, inversion, transformation, and elementary operations (menu options 8, 11, 13, 14, and 16), respectively, require the execution of other programs, lines 930-1010.

The matrix addition/subtraction subroutine, lines 6500-6700, stores the first matrix entered in variables B(.,.), RB, and CB, lines 6570-6602. The second matrix is retained in A(.,.), R, and C after it is entered into memory in line 6604. Conformation of matrices is tested in 6614, and the operation is performed, lines 6640-6670. If variable S = 1, subtraction is performed; in other cases, addition is done.

Scalar/matrix operations are performed in lines 6900-6950. Variable IT = 1 signifies multiplication and IT = 2 signifies addition (line 6932). The multiplier is stored in variable M and the scalar addition value is stored in variable AS (line 6935). Subtraction is done if AS is negative. In line 6940, you must respond to select the portion of the matrix targeted for the operation: row (lines 8000-8020), column (lines 8100-8120), or all elements (lines 8200-8210). The operation is performed in lines 8010, 8110, and 8200. An error check for missing values, MV, disallows operation on them.

Transposition is accomplished in lines 7500-7660. The only complicated part of this routine occurs in line 7645 which causes the now invalid column names to be changed into numeral names representing that column.

Finally, the routine to enter special matrices is defined in lines 10100-10190. This routine allows creation of diagonal matrices by entering only the diagonal values instead of every element (lines 10140-10190). Matrices in which all elements are the same number may also be created in this routine (lines 10130-10135).

Program ALTER (Appendix III)

Through ALTER, you can change an element of the data matrix (lines 4200-4260), delete a column (lines 4500-4610), delete a row (lines 4800-4910), add a column (lines 5100-5170), add a row (lines 5400-5470), create a new row/column with a fixed value (lines 6000-6080), set parts of a row/column to a fixed value (lines 6090-6180), merge two matrices (lines 7000-7310), and extract any portion of a matrix to create a new one (lines 8000-8130). These subroutines are extremely simple. It should be equally simple to add operations if necessary. As in the MAIN program, one matrix is always stored in A(.,.) with column names in N$(.). A second matrix, if needed, is stored in B(.,.) and its column names are stored in NB$(.).

Program MATMULT (Appendix IV)

This program allows matrix multiplication (lines 7300-7480). It is a separate program in order to allow the largest possible matrices to be multiplied together. There is an error check (line 7345) for conformability of matrices under multiplication. The original column names no longer apply after multiplication (line 7470).

Program INVERSE (Appendix V)

This inversion routine (lines 8500-9526) was adapted from the program presented by Hornbeck (1975). The routine uses Gauss-Jordan elimination with column shifting to maximize pivot elements. The matrix to be inverted must be square, nonsingular, and of order 50 or less. The only error trap is in line 9312, which checks to see if the determinant of the matrix is zero to within six digits. This criterion could easily be changed. The Euclidean norm of the matrix is computed and stored in PD; DTNRM holds the value for the determinant, DETM, divided by PD. Extreme ill-conditioning or singularity will usually be accompanied by a small value of DTNRM (Hornbeck 1975).

Program TRNSFORM (Appendix VI)

Program TRNSFORM allows data elements to be transformed by various functions (lines 10000-10640). Many other transformation functions are possible and can easily be inserted. Transformations may now only be performed on the entire data matrix, not on selected rows or columns.

Program ELEMOPS (Appendix VII)

Program ELEMOPS allows elementary row/column operations plus the interchanging of any two rows or columns. The code to accomplish these tasks is clear and needs no additional documentation. The loop in line 10000 is used as a time delay loop.

Recovery From Errors

The most serious errors will terminate the program. The most effective recovery technique is simply to enter <GOTO 700>, re-activating the program by switching control to the current menu. The data containing the work done up to the error will still be active in memory as can be seen by entering option <6> to display it. You can save the current work, take stock of the situation, and try again. Although this procedure does not correct the error, it does save your time. Most errors will probably result from a conflict between the maximum dimensions allowed as defined in line 40000 and the current requirements. The solution is to adjust the dimensions of line 40000 if they differ from the current needs.

APPENDIX I. Source code listing for program SEED/BAS

```
13 '**************************************************
14 'ANSWER INPUT ROUTINE
15 P=(256*PEEK(16417)+PEEK(16416))-15359
     :IF ABS(FL)=1THEN16ELSE24
16 IN$=""
     :PRINT@P,CHR$(136);
     :LX=1
17 IN$=INKEY$
     :IFIN$=""THEN22
18 IFFL=-1 AND ASC(IN$)>47 AND ASC(IN$)<58 THEN 21
19 IF FL=1 AND ASC(IN$)>64 AND ASC(IN$)<91 THEN 21
20 GOTO 22
21 PRINT@P,IN$
     :RETURN
22 LX=LX+1
     :IFL<16THEN17
23 PRINT@P," ";
     :FORLX=1TO25
     :NEXT
     :GOTO16
24 PRINT@P, CHR$(136);
     :IN$=""
     :LX=ABS(FL)
     :GOSUB34
25 A$=INKEY$
     :IFA$=""THEN25
26 IFA$=CHR$(13)THENPRINTCHR$(15);
     :RETURN
27 IF A$=CHR$(8)THENIFIN$<>""THENPRINTA$;
     :PRINTCHR$(136);CHR$(24);
     :IN$=LEFT$(IN$,LEN(IN$)-1)
     :LX=LX+1
     :GOTO25
     :ELSEGOTO28
28 IFA$=CHR$(24)THENPRINTCHR$(29);
     :GOTO24
29 IF FL>0 AND ASC(A$)>31 AND ASC(A$)<91 THEN 32
30 IF FL<0 AND ASC(A$)>=45 AND ASC(A$)<58 THEN 32
31 GOTO 25
32 IF LX=0 THEN 25
33 PRINT A$;
     :IN$=IN$+A$
     :LX=LX-1
     :GOTO25
34 FOR IX=1TOLX-1
     :PRINT CHR$(136);
     :NEXT
     :FORJX=1TOLX
     :PRINT CHR$(24);
     :NEXT
     :RETURN
36 '*****************************************
37 'MENU SELECTOR ROUTINE BY FRANK B. ROWLETT, JR.
38 '80 MICROCOMPUTING 1(11)
     :195  NOV. 1980
```

```
40 'ON OUTPUT X=ITEM # SELECTED USES X,X0,X1,X2,X3 AND B$
41 '/////////////////////////
42 X1=X
     :PRINT@960,CHR$(30);"[ MOVES INDICATOR UP, ";CHR$(92);" MOVES IND
      CATOR DOWN, <ENTER> TO SELECT";
43 PRINT@X1,CHR$(143);
     :FORX2=0TO2
     :B$=INKEY$
     :IFB$=""THENNEXTX2
     :PRINT@X1,CHR$(94);
     :FORX2=0TO9
     :B$=INKEY$
     :IFB$=""THENNEXTX2
     :GOTO43
44 PRINT@X1," ";
     :X2=ASC(B$)
     :IFX2=91THEN45ELSEIFX2=10THEN46ELSEIFX2=13THENPRINT@X1,CHR$(94);
     :X=(X1-X)/64+1
     :RETURNELSE43
45 X3=0
     :X1=X1-64
     :IFX1<XTHENX1=X+(X0-1)*64
     :GOTO47ELSE47
46 X3=0
     :X1=X1+64
     :IFX1=X+X0*64THENX1=X
47 PRINT@X1,CHR$(143);
     :FORX2=0TO5
     :NEXTX2
     :PRINT@X1,CHR$(94);
     :FORX2=0TO19
     :NEXTX2
     :IFX3<2THENX3=X3+1
     :GOTO47ELSEX3=PEEK(14656)
     :PRINT@X1," ";
     :IFX3=8THEN45ELSEIFX3=16THEN46ELSE43
50 '*************************************
52 'CHANGE VARIABLE NAMES
54 '///////////////
56 CLS
     :PRINT@448,"WHICH COLUMN'S NAME WILL BE CHANGED? --> ";
     :FL=-2
     :GOSUB15
     :XJ=VAL(IN$)
     :PRINT
     :PRINT"PLEASE ENTER NEW NAME --> ";
     :FL=8
     :GOSUB15
     :N$(XJ)=IN$
     :RETURN
100 '****************************************
110 'READ SEQUENTIAL DATA SET FROM DISK
120 '///////////////////
130 CLS
135 PRINT@448,"ENTER FILENAME OF DESIRED DATA SET --> ";
```

```
    :8,"ENTER FILENAME OF DESIRED DATA SET --> ";
    :INPUT F$
    :FF$=F$+"N"
    :L$=F$+"L"
    :F$=F$+"M"
140 OPEN "I",1,FF$
    :INPUT#1,R,C
    :CLOSE1
    :'GET R,C VALUES
145 OPEN "I",1,L$
    :FORK=1TOC
    :INPUT#1,N$(K)
    :NEXTK
146 CLOSE
150 OPEN "I",1,F$
    :
160 FORI=1TOR
    :FORJ=1TOC
    :INPUT#1,A(I,J)
    :NEXTJ,I
170 CLOSE 1
180 RETURN
190 '**********************************************
200 ' WRITE A SEQUENTIAL MATRIX TO DISK
210 '//////////////////
220 CLS
    :PRINT@448,"ENTER FILENAME OF NEW DATA SET --> ";
    :INPUT F$
    :PRINT
    :PRINT"ENTER DISK DRIVE # WHERE DATA SHOULD BE SAVED --> ";
    :INPUT DD$
    :FF$=F$+"N:"+DD$
    :L$=F$+"L:"+DD$
    :F$=F$+"M:"+DD$
225 FOR JQ=1TOC
    :IF LEN(N$(JQ))=0 THEN N$(JQ)=STR$(JQ)
226 NEXT
230 OPEN "O",1,FF$
    :PRINT#1,R;C;
    :CLOSE1
240 OPEN "O",1,F$
    :
250 FORI=1TOR
    :FORJ=1TOC
    :PRINT#1,A(I,J);
    :NEXTJ,I
260 CLOSE 1
265 OPEN"O",1,L$
    :FORI=1TOC
    :PRINT#1,N$(I);",";
    :NEXT
    :CLOSE
270 RETURN
290 REM ***************************************************
295 REM               SUBROUTINE INPUT
```

```
300 '1.  THIS SUB READS FROM THE KEYBOARD
305 '2.  MATRIX A IS LOADED AND CAN BE SAVED ON DISK
325 '6.  14-APR-79
335 REM ****************************************************
340 CLS
345 INPUT "PLEASE ENTER: NO. ROWS AND COLS (R,C).--> ";R,C
350 FL=8
     :PRINT
     :FOR J=1TOC
     :PRINT"ENTER THE NAME FOR VARIABLE ";J;" --> ";
     :GOSUB15
     :N$(J)=IN$
     :PRINT
     :NEXT
355 CLS
365 FOR I=1 TO R
370 PRINT "ROW ";I
375 FOR J=1 TO C
380 FL=-12
     :PRINT "PLEASE ENTER:  VALUE OF COLUMN ";J" --> ";
     :GOSUB 15
385 PRINT
390 A(I,J)=VAL(IN$)
395 NEXT J
400 NEXT I
430 RETURN
435 END
440 '****************************************************
445 '         SUBROUTINE VIDEO
450 '  DISPLAYS MATRIX A(R,C),13 ROWS BY 4 COLUMNS AT ONCE
455 ' USES ARROWS IN ALL DIRECTIONS TO SEE DIFFERENT PAGES
460 ' OF DATA.  "CLEAR" WILL TERMINATE DISPLAY
500 '******************************************************
510 CLS
     :IFR=0 OR C=0 THEN RETURN ELSE JJ=INT(C/4.1+1)
515 IFINT(R/13)=R/13THENII=R/13ELSEII=INT(R/13+1)
517 I=1
     :J=1
525      IF R-13*I>=0.0 THEN N=13 ELSE N=13+(R-13*I)
535      IF C-4*J>=0.0 THEN L=4 ELSE L=4+(C-4*J)
540 CLS
     :PRINT"COL:";
     :FOR KK=0TO(L-1)
     :PRINT TAB(14*KK+8) N$((KK+1)+4*(J-1));
545 NEXT KK
     :PRINT
550 PRINT"------------------------------------------------------
      -------"
555 FOR M=1 TO N
560 PRINT "R";M+13*(I-1);":";
565 FOR K=1 TO L
570 A=A(M+13*(I-1),K+4*(J-1))
575 PRINT TAB(14*(K-1)+8) A;
580 NEXT K
     :PRINT
585 NEXT M
```

```
586 A$=INKEY$
     :IFA$=""GOTO586
587 IF ASC(A$)=31THEN619ELSEIFASC(A$)=9THEN588ELSE590
588 IFJ+1>JJTHENJ=1ELSEJ=J+1
589 GOTO 525
590 IF ASC(A$)=8THEN591ELSE593
591 IF J-1<=0THENJ=JJ ELSE J=J-1
592 GOTO 525
593 IF ASC(A$)=10THEN594ELSE596
594 IF I+1>IITHENI=1ELSEI=I+1
595 GOTO 525
596 IF ASC(A$)=91THEN597ELSE601
597 IF I-1<=0THENI=IIELSEI=I-1
598 GOTO 525
601 IF ASC(A$)=46 THEN GOSUB 50 ELSE 618
602 GOTO 525
618 GOTO586
619 RETURN
     :END
620 '*****************************************************
622 'LINEPRINTER OUTPUT ROUTINE
623 IF R=0 OR C=0 THEN RETURN
624 AN$="DATA SET NAME --> "
     :CLS
     :PRINT@448,"PRESS <ENTER> WHEN PRINTER IS READY.";
     :INPUT AN
626 PRINT
     :PRINT"PLEASE ENTER NAME OF DATA SET --> ";
     :FL=20
     :GOSUB15
     :T$=AN$+IN$
     :PRINT
     :PRINT
     :GOSUB42000
     :LPRINT TAB(ZZ);IN$
     :LPRINT" "
     :LPRINT" "
630 JJ=INT(C/4.1+1)
     :II=INT(R/200.1+1)
632 FORI=1TOII
634 IFR-200*I>=0.0THENN=200ELSEN=200+(R-200*I)
636 FORJ=1TOJJ
638 IFC-4*J>=0.0THENL=4ELSE L=4+(C-4*J)
640 LPRINT"COL:";
     :FORKK=0TO(L-1)
     :LPRINT TAB(14*KK+8) N$((KK+1)+4*(J-1));
642 NEXT KK
644 LPRINT" "
646 LPRINT"------------------------------------------------------
      --------"
648 FOR M=1TON
650 LPRINT "R";M+200*(I-1);":";
652 FOR K=1TO L
654 A=A(M+200*(I-1),K+4*(J-1))
656 LPRINT TAB(14*(K-1)+8) A;
658 NEXT K
```

```
660 LPRINT
662 NEXT M
664 LPRINT " "
      :LPRINT " "
      :LPRINT " "
666 NEXT J,I
668 RETURN
670 CLS
      :PRINT@448,"THE CURRENT DATA MATRIX IN MEMORY WILL BE LOST."
      :PRINT
      :PRINT"DO YOU WISH TO (S)AVE IT OR (C)ONTINUE --> ";
      :FL=1
      :GOSUB15
      :IFIN$="S"THENGOSUB190ELSEIFIN$="C"THEN680ELSE670
680 RETURN
40000 DIM A(150,20),N$(20),B(150,20)
40015 MV=-99.99
40020 RETURN
42000 CC=LEN(T$)
      :ZZ=INT(30-CC/2)
      :PRINT TAB(ZZ);T$
      :RETURN
      :'CENTERING ROUTINE
43000 END
```

APPENDIX II. Source code listing for program MAIN/BAS

```
10 CLEAR 500
     :TX=-1
     :GOTO700
     :'NUMERICAL INFORMATION MANIPULATION SYSTEM  02/04/81
695 RETURN
700 '***************************************************
710 'GENERALIZED I/O SUBROUTINES FOR PROGRAM STARTERS
720 '////////////////////
735 CLS
     :T$="NORTHERN HARDWOODS LABORATORY, US FOREST SERVICE"
     :GOSUB42000
736 T$="/////////////////////////////////////////////////////"
     :GOSUB42000
737 PRINT
738 T$="MENU FOR:   NUMERICAL INFORMATION MANIPULATION SYSTEM"
739 GOSUB42000
     :PRINT
740 IF TX=-1 THEN GOSUB 40000 ELSE 750
750 TX=1
     :PRINT"  1.  RETURN TO MAIN MENU         2.  GOTO BASIC
760 PRINT"  3.  READ A MATRIX FROM DISK     4.  WRITE A MATRIX TO
       DISK
770 PRINT"  5.  ENTER A MATRIX MANUALLY     6.  DISPLAY MATRIX ON
       VIDEO
780 PRINT"  7.  PRINT MATRIX                8.  ALTER MATRIX
790 PRINT TAB(2) "9.  ADD/SUB TWO MATRICES";TAB(33) "10.  SCALAR/
      MATRIX OPERATIONS"
800 PRINT TAB(1) "11.  MATRIX MULTIPLY";TAB(33) "12.  TRANSPOSE A
       MATRIX"
810 PRINT TAB(1) "13.  INVERSE OF A MATRIX";TAB(33) "14.  TRANSFO
      RM DATA"
820 PRINT TAB(1) "15.  CREATE SPECIAL MATRICES";TAB(33) "16.  ROW
      /COL OPERATIONS"
900 PRINT
     :PRINT"SELECT ONE OF THE ABOVE --> ";
     :FL=-2
     :GOSUB15
     :AN=VAL(IN$)
     :IFAN<=0ORAN>16THEN740
905 IF R=0 OR C=0 THEN 910 ELSE IF AN=1 OR AN=2 OR AN=3 OR AN=5 O
      R AN=8 OR AN=11 OR AN=13 OR AN=14 OR AN=16 THEN GOSUB 670
910 ON AN GOSUB 695,43000,130,220,340,510,620,930,6500,6900,960,7
      500,980,990,10100,1010
920 GOTO 735
930 RUN"ALTER/BAS"
     :END
960 RUN"MATMULT/BAS"
     :END
980 RUN"INVERSE/BAS"
     :END
990 RUN"TRNSFORM/BAS"
     :END
1010 RUN"ELEMOPS/BAS"
     :END
6500 '******************************************************
```

```
6504 '            SUBROUTINE  ADDSUB
6508 '1.  ADDS B+C OR SUBTRACTS B-C
6512 '2.  OUTPUTS RESULTANT AS A
6513 '////////////////////
6532 CLS
     :PRINT"THIS ROUTINE ADDS OR SUBTRACTS MATRICES."
     :PRINT
     :PRINT"PLEASE ENTER:  (A)DD MATRIX B+C OR (S)UBTRACT  B-C --> ";
     :FL=1
     :GOSUB15
     :IFIN$="A"THENS=1ELSEIFIN$="S"THENS=2ELSE6532
6534 PRINT
6536 PRINT"ENTER MATRIX B FROM (1) DISK (2) KEYBOARD OR (3) ALREA
      DY IN MEMORY --> ";
     :FL=-1
     :GOSUB15
     :AN=VAL(IN$)
     :ON AN GOSUB 130,340,6690
6560 '    LOAD FIRST MATRIX INTO B
6570 FOR I=1 TO R
6580 FOR J=1 TO C
6590 B(I,J)=A(I,J)
6600 NEXT J,I
6602 RB=R
     :CB=C
6604 PRINT
     :INPUT"PLEASE ENTER: C FROM 1=DISK, 2=KEYBOARD, 3=ALREADY LOADED
      NN
     :ON NN GOSUB 130,340,6690
6614 IF RB<>R OR CB<>C THEN 6616 ELSE 6640
6616 PRINT"MATRICES DO NOT CONFORM TO ADDITION/SUBTRACTION."
     :GOTO 6500
6630 '      ADDITION ROUTINE
6640 FOR I=1 TO R
6650 FOR J=1 TO C
6652 IF S=1 THEN 6660
6654 A(I,J)=B(I,J)-A(I,J)
6656 GOTO 6670
6660 A(I,J)=A(I,J)+B(I,J)
6670 NEXT J,I
6680 PRINT
6690 RETURN
6700 FOR I=1TOR
     :FORJ=1TOC
     :A(I,J)=B(I,J)
     :NEXT J,I
     :RETURN
6900 '**************************************************
6902 '      SUBROUTINE SCAMULT
6904 '1.  MULTIPLIES A MATRIX BY A SCALAR
6906 '2.  OUTPUTS MATRIX A AS A RESULTANT
6908 '3.  H.M. RAUSCHER     15-APR-79
6910 '4.  15-APR-79
6930 IF R=0 OR C=0 THEN RETURN
     :'CHECK FOR NO MATRIX IN MEMORY
```

```
6932 CLS
    :PRINT@448,"ENTER (M)ULTIPLY OR (A)DD/SUBTRACT BY A SCALAR VALUE -
     -> ";
    :INPUT A$
    :IFA$="M"THENIT=1ELSEIFA$="A"THENIT=2ELSEGOTO6932
6935 CLS
    :IFIT=1THENPRINT@448,"ENTER VALUE OF SCALAR MULTIPLIER --> ";
    :INPUTM
    :ELSEIFIT=2THENPRINT@448,"ENTER VALUE (+/-) OF SCALAR CONSTANT TO
     ADD/SUBTRACT --> ";
    :INPUTAS
    :ELSE6935
6940 CLS
    :PRINT@448,"OPERATE ON A SINGLE (R)OW, (C)OLUMN OR (A)LL ELEMENTS
     --> ";
    :INPUTA$
    :IFA$="R"THENGOSUB8000ELSEIFA$="C"THENGOSUB8100ELSEIFA$="A"THENGOS
     UB8200ELSE6940
6950 RETURN
7500 '*************************************************************
7502 '          SUBROUTINE TRANSPO
7504 '1.  TRANSPOSES A MATRIX
7506 '2.  OUTPUTS MATRIX A
7508 '3.  CALLS DISKREAD,KEYBOARD
7510 '4.  H.M. RAUSCHER        15-APR-79
7512 '5.  15-APR-79
7520 IF R=0 OR C=0 THEN RETURN
    :'CHECK FOR NO MATRIX IN MEMORY
7560 FOR I=1 TO R
7570 FOR J=1 TO C
7580 B(J,I)=A(I,J)
7590 NEXT J,I
7595 TE=R
    :R=C
    :C=TE
7600 '    LOAD RESULT FROM B TO A
7610 FOR I= 1 TO R
7620 FOR J=1 TO C
7630 A(I,J)=B(I,J)
7640 NEXT J
7641 NEXT I
7645 GOSUB7660
    :'STANDARDIZE COLUMN NAMES
7650 RETURN
7660 FOR I=1TOC
    :N$(I)=STR$(I)
    :NEXTI
    :RETURN
8000 CLS
    :PRINT@448,"ENTER ROW NUMBER TO OPERATE ON --> ";
    :INPUT I
    :IFI>RORI<1THEN8000ELSE8010
8010 FORJ=1TOC
    :IFA(I,J)=MVTHEN8015ELSEIFIT=1THENA(I,J)=M*A(I,J)ELSEA(I,J)=AS+A(I
     ,J)
```

```
8015 NEXTJ
8020 RETURN
8100 CLS
     :PRINT@448,"ENTER COLUMN NUMBER TO OPERATE ON --> ";
     :INPUTJ
     :IFJ>CORJ<1THEN8100ELSE8110
8110 FORI=1TOR
     :IFA(I,J)=MVTHEN8115ELSEIFIT=1THENA(I,J)=M*A(I,J)ELSEA(I,J)=AS+A
      ,J)
8115 NEXT I
8120 RETURN
8200 FORI=1TOR
     :FORJ=1TOC
     :IFA(I,J)=MVTHEN8205ELSEIFIT=1THENA(I,J)=M*A(I,J)ELSEA(I,J)=AS+A
      ,J)
8205 NEXTJ,I
8210 RETURN
10100 '****************************************************
10105 'SUBROUTINE TO ENTER SPECIAL MATRICES
10110 '////////////////////
10120 CLS
      :PRINT@448,"WHICH TYPE OF DATA MATRIX DO YOU WANT TO CREATE?"
      :PRINT@582,"DIAGONAL MATRIX"
      :PRINT@646,"MATRIX WITH ALL ELEMENTS THE SAME VALUE"
      :X=580
      :X0=2
      :GOSUB36
      :IFX=1THEN10140
10130 CLS
      :PRINT@448,"ENTER THE ROW DIMENSION --> ";
      :FL=-3
      :GOSUB15
      :R=VAL(IN$)
      :PRINT
      :PRINT"ENTER THE COLUMN DIMENSION --> ";
      :GOSUB15
      :C=VAL(IN$)
      :PRINT
      :PRINT"ENTER THE VALUE FOR ALL ELEMENTS --> ";
      :FL=-12
      :GOSUB15
      :AA=VAL(IN$)
10135 PRINT
      :PRINT"COMPUTATIONS IN PROGRESS."
      :FORJ=1TOC
      :N$(J)=STR$(J)
      :FORI=1TOR
      :A(I,J)=AA
      :NEXTI,J
      :RETURN
10140 CLS
10145 PRINT"LOAD INTO MEMORY A 1XC ROW MATRIX OF DIAGONALS."
10147 PRINT
10150 PRINT"ENTER MATRIX FROM (1) DISK (2) KEYBOARD OR (3) IN MEM
      ORY --> ";
     :ENTER MATRIX FROM (1) DISK (2) KEYBOARD OR (3) IN MEMORY --> ";:F
      L=-1:GOSUB15:AN=VAL(IN$):ON AN GOSUB 130,340,10190
10152 IF R<>1 PRINT
     :PRINT"MATRIX IS NOT 1XC."
     :PRINT
     :GOTO10145
10155 R=C
     :FOR I=1 TOR
     :FOR J=1 TO C
10160 B(I,J)=0
     :IF I=J THEN B(I,J)=A(1,J)
10165 NEXT J
10170 NEXT I
10175 '     LOAD MATRIX A
10180 FOR I=1 TO R
     :FOR J=1 TO C
     :A(I,J)=B(I,J)
     :NEXT J
     :NEXT I
10190 RETURN
40000 DIM A(150,20),N$(20),B(150,20)
40015 MV=-99.99
40020 RETURN
42000 CC=LEN(T$)
     :ZZ=INT(30-CC/2)
     :PRINT TAB(ZZ);T$
     :RETURN
     :'CENTERING ROUTINE
43000 END
```

APPENDIX III. Source code listing for program ALTER/BAS

```
10 CLEAR 500
     :TX=-1
     :GOTO700
     :'ALTER/BAS   VERSION 03/17/81
695 RUN"MAIN/BAS"
     :END
700 '***************************************************
710 'GENERALIZED I/O SUBROUTINES FOR PROGRAM STARTERS
720 '//////////////////
735 CLS
     :T$="NORTHERN HARDWOOD LABORATORY, US FOREST SERVICE"
     :GOSUB42000
736 T$="///////////////////////////////////////////////////////"
     :GOSUB42000
     :PRINT
739 T$="MENU FOR:      MATRIX ALTERATION ROUTINE"
     :GOSUB42000
     :PRINT
740 IF TX=-1 THEN GOSUB 40000 ELSE 750
750 TX=1
     :PRINT"  1.  RETURN TO MAIN MENU         2.  GOTO BASIC
760 PRINT"  3.  READ A MATRIX FROM DISK      4.  WRITE A MATRIX TO
       DISK
770 PRINT"  5.  ENTER A MATRIX MANUALLY      6.  DISPLAY MATRIX ON
       VIDEO
780 PRINT TAB(2) "7.  PRINT MATRIX";TAB(34) "8.  CHANGE AN ELEMEN
      T"
790 PRINT TAB(2)"9.  DELETE A COLUMN";TAB(33)"10.  DELETE A ROW"
800 PRINT TAB(1)"11.  ADD A COLUMN";TAB(33)"12.  ADD A ROW"
810 PRINT TAB(1)"13.  ADD FIXED VALUE ROW/COL";TAB(33)"14.  CHANG
      E R/C TO FIXED VAL."
820 PRINT TAB(1)"15.  MERGE TWO MATRICES";TAB(33)"16.  SPLIT A MA
      TRIX"
900 PRINT
     :PRINT"SELECT ONE OF THE ABOVE --> ";
     :FL=-2
     :GOSUB15
     :AN=VAL(IN$)
905 IF R=0 OR C=0 THEN 910 ELSE IF AN=1 OR AN=2 OR AN=3 OR AN=5 T
      HEN GOSUB 670
910 ON AN GOSUB 695,43000,130,220,340,510,620,4200,4500,4800,5100
      ,5400,6000,6090,7000,8000
920 GOTO 720
4200 '      ALTER ONE ELEMENT OF A MATRIX
4201 CLS
4210 INPUT "PLEASE ENTER: LOCATION OF ELEMENT TO BE CHANGED (ROW,
      COL).";M,N
4220 PRINT
4230 PRINT "MATRIX (R,C)= (";M;",";N;")=";A(M,N)
4240 PRINT
4250 INPUT "PLEASE ENTER:  NEW VALUE OF ELEMENT.";Z
     :A(M,N)=Z
4260 GOTO 5900
4500 '      DELETE ONE COLUMN
4501 CLS
```

```
4510 INPUT"PLEASE ENTER:  COLUMN TO BE DELETED.";M
4512 IF M>C PRINT"SORRY. COLUMN OUTSIDE OF RANGE." ELSE 4520
4514 GOTO 4510
4520 IF M < C GOTO 4540
4530 C=C-1
     :GOTO 4600
4540 FOR J1=M TO C
4550 FOR I1=1 TO R
4560 IF J1=C GOTO 4565 ELSE GOTO 4570
4565 C=C-1
     :GOTO 4600
4570 A(I1,J1)=A(I1,J1+1)
4580 NEXT I1
4590 NEXT J1
4600 FOR J=MTOC
     :N$(J)=N$(J+1)
     :NEXT
     :GOTO5900
4610 STOP
4800 '        DELETE ONE ROW
4801 CLS
4810 INPUT"PLEASE ENTER:  ROW TO BE DELETED.";M
4812 IF M>R PRINT"SORRY. OUTSIDE OF RANGE." ELSE 4820
4814 GOTO 4810
4820 IF M < R GOTO 4840
4830  R=R-1
     :GOTO 4900
4840 FOR I=M TO R
4850 FOR J=1 TO C
4860 IF I=R GOTO 4830
4870 A(I,J)=A(I+1,J)
4880 NEXT J
4890 NEXT I
4900 GOTO 5900
4910 STOP
5100 '       ADD A COLUMN
5101 CLS
5105 PRINT"MATRIX HAS DIMENSIONS (R,C)=(";R;",";C;")"
5107 FL=8
     :PRINT
     :PRINT"ENTER THE NAME FOR VARIABLE ";C+1;" --> ";
     :GOSUB15
     :N$(C+1)=IN$
     :PRINT
5110 FOR I=1 TO R
5120 PRINT"PLEASE ENTER: VALUE OF ROW ";I;" COLUMN ";C+1;
5130 INPUT A(I,C+1)
5140 NEXT I
5150 C=C+1
5160 GOTO 5900
5170 STOP
5400 '          ADD ONE ROW
5401 CLS
5402 PRINT"A ROW MAY NOT BE INSERTED BETWEEN OTHER ROWS."
5410 PRINT "MATRIX HAS DIMENSIONS (R,C)=(";R;",";C;")"
```

```
5420 FOR J=1 TO C
5430 PRINT"PLEASE ENTER: VALUE OF ROW";R+1;"COLUMN";J;
5440 INPUT A(R+1,J)
5450 NEXT J
5460 R=R+1
     :GOTO 5900
5470 STOP
5900 RETURN
     :'TO MAIN MENUE
6000 '  CREATE A NEW ROW OR COLUMN WITH FIXED VALUE
6010 CLS
     :INPUT"ADD A (1) ROW OR (2) COLUMN WITH FIXED VALUE";EX
6020 INPUT"WHAT IS THE NEW VALUE";NV
6025 IFEX=2THENPRINT
     :FL=8
     :PRINT"ENTER THE NAME FOR VARIABLE ";C+1;" --> ";
     :GOSUB15
     :N$(C+1)=IN$
     :PRINT
     :ELSE 6030
6030 IF EX=1 THEN EY=C
6032 IF EX=2 THEN EY=R
6040 FOR I=1TOEY
6050 IF EX=1 THEN A(R+1,I)=NV
6052 IF EX=2 THEN A(I,C+1)=NV
6060 NEXT I
6070 IF EX=1 THEN R=R+1
6072 IF EX=2 THEN C=C+1
6080 RETURN
6090 '  SET PARTS OF ROWS OR COLUMNS TO PARTICULAR VALUES
6100 CLS
     :INPUT"CHANGE PORTIONS OF A (1) ROW OR (2) COLUMN";EX
6110 INPUT"WHAT IS THE NEW VALUE";NV
6120 INPUT"WHICH ROW/COLUMN IS TO BE CHANGED";J
6130 INPUT"BEGIN CHANGE AT LOCATION";ES
6140 INPUT"END CHANGE AT LOCATION";EF
6150 FOR I=ES TO EF
6160 IF EX=1 THEN A(J,I)=NV
6162 IF EX=2 THEN A(I,J)=NV
6170 NEXT I
6180 RETURN
7000 '***********************************************
7010 'ROUTINE TO MERGE TWO MATRICES
7020 'A IS STORED IN MEMORY ALREADY, B IS LOADED IN
7030 IF R=0 OR C=0 THEN RETURN
     :'CHECK FOR NO MATRIX IN MEMORY
7035 CLS
7040 'TRANSFER A-->B
7050 FORI=1TOR
     :FORJ=1TOC
     :B(I,J)=A(I,J)
     :NEXTJ,I
     :RA=R
     :CA=C
     :FORJ=1TOC
```

```
    :OR
    :FORJ=1TOC
    :B(I,J)=A(I,J)
    :NEXTJ,I
    :RA=R
    :CA=C
    :FORJ=1TOC
    :NB$(J)=N$(J)
    :NEXTJ
7060 PRINT@256,"THE CORE MATRIX IS IN MEMORY. READ THE SECOND MAT
     RIX FROM DISK."
7070 GOSUB135
    :RB=R
    :CB=C
7080 CLS
    :PRINT@448,"THE CORE (A) MATRIX HAS DIMENSIONS --> ";RA;" BY ";CA
7090 PRINT"THE SECOND (B) MATRIX HAS DIMENSIONS --> ";RB;" BY ";C
     B
7100 PRINT
    :INPUT"MERGE A WITH B BY (1) ROWS OR (2) COLUMNS --> ";IA
7110 IF IA=1THEN7120ELSEIFIA=2THEN7200ELSE7100
7120 C=FNMAX(CA,CB)
    :R=RA+RB
    :'ROW MERGE
7130 FORI=1TOR
    :FORJ=1TOC
7135 IF I<=RA AND J>CA THEN B(I,J)=0
7140 IF I>RA AND J<=CB THEN B(I,J)=A(I-RA,J)
7145 IF I>RA AND J>CB THEN B(I,J)=0
7150 NEXT J,I
7160 IF C=CA THEN 7300
7170 FOR J=CA+1 TO C
    :N$(J)=STR$(J)
    :NEXTJ
    :GOTO7300
7200 R=FNMAX(RA,RB)
    :C=CA+CB
    :'COLUMN MERGE
7210 FORJ=1TOC
    :FORI=1TOR
7215 IF J<=CA AND I>RA THEN B(I,J)=0
7220 IF J>CA AND I<=RB THEN B(I,J)=A(I,J-CA)
7225 IF J>CA AND I>RB THEN B(I,J)=0
7230 NEXTI,J
7240 FORJ=CA+1TOC+CB
    :NB$(J)=N$(J-CA)
    :NEXT
    :FORJ=1TOC
    :N$(J)=NB$(J)
    :NEXTJ
7300 FORI=1TOR
    :FORJ=1TOC
    :A(I,J)=B(I,J)
    :NEXTJ,I
7310 RETURN
```

```
8000 '******************************************
8010 'ROUTINE TO EXTRACT ANY PORTION OF A MATRIX OUT
8020 'OF AN EXISTANT ONE AND DEFINE IT AS AN INDEPENDENT
8030 'MATRIX
8040 '//////////////////////////////
8050 IF R=0 OR C=0 THEN RETURN
     :'CHECK FOR RESIDENCE OF A MATRIX
8060 CLS
     :PRINT@448,"THE MATRIX IN MEMORY HAS "R" ROWS AND "C" COLUMNS.
     :PRINT
     :PRINT"ENTER THE ROW,COLUMN COORDINATES OF THE UPPER LEFT"
     :PRINT"CORNER OF THE NEW MATRIX (R,C) --> ";
     :INPUT RU,CU
8070 IF RU<1 OR RU>R OR CU<1 OR CU>C THEN 8060
     :'ERROR CHECK
8080 PRINT
     :PRINT"ENTER THE ROW,COLUMN COORDINATES OF THE LOWER RIGHT"
     :PRINT"CORNER OF THE NEW MATRIX (R,C) --> ";
     :INPUT RL,CL
     :IFRL<1 OR RL>R OR RL<RU OR CL<1 OR CL>C OR CL<CU THEN 8080
     :'ERROR CHECK
8090 FORJ=1TOC
     :NB$(J)=N$(J)
     :NEXT
     :'PRESERVE COLUMN NAMES
8100 FORI=RUTORL
     :FORJ=CUTOCL
     :B(I-RU+1,J-CU+1)=A(I,J)
     :NEXTJ,I
     :C=CL-CU+1
     :R=RL-RU+1
     :'EXTRACT NEW MATRIX
8110 FORJ=1TOC
     :N$(J)=NB$(CU+J-1)
     :NEXTJ
     :'RETAIN COLUMN NAMES
8120 FORI=1TOR
     :FORJ=1TOC
     :A(I,J)=B(I,J)
     :NEXTJ,I
     :'LOAD NEW MATRIX INTO A()
8130 RETURN
40000 DIM A(370,2),N$(20),B(370,2),NB$(20)
40010 MV=-99.99
40012 DEF FNMIN(A,B)=(A+B-ABS(A-B))/2
     :'MINIMUM OF A,B
40014 DEF FNMAX(A,B)=(A+B+ABS(A-B))/2
     :'MAXIMUM OF A,B
40020 RETURN
42000 CC=LEN(T$)
     :ZZ=INT(30-CC/2)
     :PRINT TAB(ZZ);T$
     :RETURN
     :'CENTERING ROUTINE
43000 END
```

APPENDIX IV. Source code listing for program MATMULT/BAS

```
10 CLEAR 500
     :TX=-1
     :GOTO700
     :'MATMULT/BAS  VERSION  02/04/81
695 RUN"MAIN/BAS"
     :END
700 '**************************************************
710 'GENERALIZED I/O SUBROUTINES FOR PROGRAM STARTERS
720 '////////////////////
735 CLS
     :T$="NORTHERN HARDWOODS LABORATORY, US FOREST SERVICE"
     :GOSUB42000
736 T$="////////////////////////////////////////////////////"
     :GOSUB42000
     :PRINT
739 T$="MENU FOR:     MATRIX MULTIPLICATION ROUTINE"
     :GOSUB42000
     :PRINT
740 IF TX=-1 THEN GOSUB 40000 ELSE 750
750 TX=1
     :PRINT"  1.  RETURN TO MAIN MENU          2.  GOTO BASIC
760 PRINT"  3.  READ A MATRIX FROM DISK      4.  WRITE A MATRIX TO
        DISK
770 PRINT"  5.  ENTER A MATRIX MANUALLY      6.  DISPLAY MATRIX ON
        VIDEO
780 PRINT TAB(2) "7.  PRINT MATRIX";TAB(34) "8.  MATRIX MULTIPLY"

900 PRINT
     :PRINT"SELECT ONE OF THE ABOVE --> ";
     :FL=-1
     :GOSUB15
     :AN=VAL(IN$)
905 IF R=0 OR C=0 THEN 910 ELSE IF AN=1 OR AN=2 OR AN=3 OR AN=5 T
       HEN GOSUB 670
910 ON AN GOSUB 695,43000,130,220,340,510,620,7300
920 GOTO 720
7300 '*************************************************
7301 '         SUBROUTINE MATMULT
7302 '1.  MULTIPLIES MATRIX B*A
7303 '2.  CALLS SUB READISK,KEYBOARD
7304 '3.  OUTPUTS MATRIX A
7305 '4.  H.M. RAUSCHER      15-APR-79
7306 '5.  15-APR-79
7310 IF R=0 OR C=0 THEN RETURN
     :'CHECK OF MATRIX IN MEMORY
7320 CLS
     :PRINT@128,"THE ORDER OF MULTIPLICATION IS B * A."
     :PRINT
     :PRINT"MATRIX B IS ALREADY IN MEMORY."
7330 RB=R
     :CB=C
7332 FOR I=1TOR
     :FORJ=1TOC
     :B(I,J)=A(I,J)
     :NEXT J,I
```

```
7335 PRINT
     :PRINT
     :PRINT"ENTER A FROM (1) DISK (2) KEYBOARD OR (3) IN MEMORY --> "
     :FL=-1
     :GOSUB15
     :AN=VAL(IN$)
     :ON AN GOSUB 130,340,7480
7340 '     TEST FOR CONFORMITY
7345 IF CB=R GOTO 7444 ELSE 7350
7350 PRINT"MATRICES NOT CONFORMABLE FOR MULTIPLICATION."
     :FOR I=1 TO 1000
     :NEXT I
     :RETURN
7442 '      MULTIPLICATION ROUTINE
7444 FOR I=1 TO RB
7446 FOR J=1 TO C
7448 S=0
7450 FOR K=1 TO CB
7452 S=S+B(I,K)*A(K,J)
7454 NEXT K
7456 C(I,J)=S
7458 NEXT J,I
7460 '       RELOAD C TO A
7462 FOR I=1 TO RB
7464 FOR J=1 TO C
7466 A(I,J)=C(I,J)
7468 NEXT J,I
7470 R=RB
     :FORI=1TOC
     :N$(I)=STR$(I)
     :NEXTI
7480 RETURN
40000 DM=45
     :DIM N$(DM),A(DM,DM),B(DM,DM),C(DM,DM)
40010 MV=-99.99
40020 RETURN
42000 CC=LEN(T$)
     :ZZ=INT(30-CC/2)
     :PRINT TAB(ZZ);T$
     :RETURN
     :'CENTERING ROUTINE
43000 END
```

APPENDIX V. Source code listing for program INVERSE/BAS

```
10 CLEAR 500
     :TX=-1
     :GOTO700
     :'INVERSE/BAS  VERSION 02/05/81
695 RUN"MAIN/BAS"
     :END
700 '****************************************************
710 'GENERALIZED I/O SUBROUTINES FOR PROGRAM STARTERS
720 '/////////////////
735 CLS
     :T$="NORTHERN HARDWOODS LABORATORY, US FOREST SERVICE"
     :GOSUB42000
736 T$="//////////////////////////////////////////////////////"
     :GOSUB42000
     :PRINT
739 T$="MENU FOR:    MATRIX INVERSION ROUTINE"
     :GOSUB42000
     :PRINT
740 IF TX=-1 THEN GOSUB 40000 ELSE 750
750 TX=1
     :PRINT"  1.  RETURN TO MAIN MENU         2.  GOTO BASIC
760 PRINT"  3.  READ A MATRIX FROM DISK     4.  WRITE A MATRIX TO
      DISK
770 PRINT"  5.  ENTER A MATRIX MANUALLY     6.  DISPLAY MATRIX ON
      VIDEO
780 PRINT TAB(2) "7.  PRINT MATRIX";TAB(34) "8.  MATRIX INVERSION
     "
900 PRINT
     :PRINT"SELECT ONE OF THE ABOVE --> ";
     :FL=-1
     :GOSUB15
     :AN=VAL(IN$)
905 IF R=0 OR C=0 THEN 910 ELSE IF AN=1 OR AN=2 OR AN=3 OR AN=5 T
     HEN GOSUB 670
910 ON AN GOSUB 695,43000,130,220,340,510,620,8500
920 GOTO 720
8500 REM ************************************************
8510 REM      SUBROUTINE FOR MATRIX INVERSION
8520 '  EMPLOYS GAUSS-JORDAN ELIMINATION WITH COLUMN
8530 '  SHIFTING TO MAXIMIZE PIVOT ELEMENTS.
8540 '
8550 '  INPUTS
     :
8560 '    A(I,I) MUST BE A SQUARE, NONSINGULAR MATRIX
8570 '    N = ORDER OF MATRIX
8580 '
8590 '  OUTPUTS
     :
8600 '    A(N,N) CONTAINS THE INVERSE
8610 '    DETM  CONTAINS THE DETERMINANT
8620 '    DTNRM  CONTAINS MAGNITUDE OF DET/EUCLIDIAN NORM
8630 '
8640 '  NOTE
     :  THIS ROUTINE TESTS FOR A SINGULAR MATRIX
8650 '         AND PRINTS AN ERROR OUT IF A(N,N) IS SINGULAR
```

```
8655 'SOURCE
     : HORNBECK, R.W. 1975. NUMERICAL METHODS. P.295
8660 REM ***************************************************
8670 IF R=0 OR C=0 THEN RETURN
     :'CHECK FOR MATRIX IN MEMORY
8680 CLS
8700 IF R<>C GOTO 9500 ELSE N=R
8702 CLS
     :PRINT@ 520,"PLEASE BE PATIENT.  I AM COMPUTING."
8710 PD=1.0
8720 FOR L=1 TO N
8730 DD=0
8740 FOR K=1 TO N
8750 DD=DD+A(L,K)*A(L,K)
8760 NEXT K
8770 DD=SQR(DD)
8780 PD=PD*DD
8790 NEXT L
8800 DETM=1.0
8810 FOR L=1 TO N
8820 J(L+20)=L
8830 NEXT L
8840 FOR L=1 TO N
8850 CC=0.0
8860 M=L
8870 FOR K=L TO N
8880 IF((ABS(CC)-ABS(A(L,K))) > 0.0) GOTO 8910
8890 M=K
8900 CC=A(L,K)
8910 NEXT K
8920 IF L=M GOTO 9010
8930 K=J(M+20)
8940 J(M+20)=J(L+20)
8950 J(L+20)=K
8960 FOR K=1 TO N
8970 S=A(K,L)
8980 A(K,L)=A(K,M)
8990 A(K,M)=S
9000 NEXT K
9010 A(L,L)=1.0
9020 DETM=DETM*CC
9030 FOR M=1 TO N
9039 ON ERROR GOTO 9380
9040 A(L,M)=A(L,M)/CC
9050 NEXT M
9060 FOR M=1 TO N
9070 IF L=M GOTO 9140
9080 CC=A(M,L)
9090 IF CC=0.0 GOTO 9140
9100 A(M,L)=0.0
9110 FOR K=1 TO N
9120 A(M,K)=A(M,K)-CC*A(L,K)
9130 NEXT K
9140 NEXT M
9150 NEXT L
```

```
9160 FOR L=1 TO N
9170 IF J(L+20) = L GOTO  9290
9180 M=L
9190 M=M+1
9200 IF J(M+20) = L GOTO 9220
9210 IF N > M GOTO 9190
9220 J(M+20)=J(L+20)
9230 FOR K=1 TO N
9240 CC=A(L,K)
9250 A(L,K)=A(M,K)
9260 A(M,K)=CC
9270 NEXT K
9280 J(L+20)=L
9290 NEXT L
9300 DETM=ABS(DETM)
9310 DTNRM=DETM/PD
9311 CLS
9312 IF DETM=0.0 GOTO 9370
9320 PRINT"THE DETERMINANT = ";DETM
9321 PRINT
     :FORI=1TOC
     :N$(I)=STR$(I)
     :NEXTI
9322 GOTO 9435
9324 END
9370 '      ROUTINE TO HANDLE A SINGULAR MATRIX
9380 CLS
9390 PRINT"I AM SORRY.  MATRIX A  IS SINGULAR."
9400 PRINT"A SINGULAR MATRIX HAS NO UNIQUE INVERSE."
9410 PRINT"IF YOU MUST GET AN INVERSE,OBTAIN A PROGRAM"
9420 PRINT"WHICH CAN CALCULATE THE PSEUDO-INVERSE OF A"
9430 PRINT"SINGULAR MATRIX.  "
9435 PRINT
9436 PRINT"PLEASE DEPRESS ANY KEY TO RETURN TO MENUE."
9437 A$=INKEY$
     :IF A$<>"" RETURN ELSE 9437
9450 END
9500 '     ERROR DUE TO NON-SQUARE MATRIX
9510 PRINT"I AM SORRY.  MATRIX ";N4;" IS NOT SQUARE AND"
9520 PRINT"CONSEQUENTLY CANNOT BE INVERTED."
9522 PRINT"PLEASE DEPRESS ANY KEY TO CONTINUE."
9524 A$=INKEY$
     :IF A$="" THEN 9524
9526 RETURN
40000 DM=50
     :DIM A(DM,DM),B(DM,DM),N$(DM),J(120)
40010 MV=-99.99
40020 RETURN
42000 CC=LEN(T$)
     :ZZ=INT(30-CC/2)
     :PRINT TAB(ZZ);T$
     :RETURN
     :'CENTERING ROUTINE
43000 END
```

APPENDIX VI. Source code listing for program TRNSFORM/BA

```
10 CLEAR 500
     :TX=-1
     :GOTO700
     :'TRNSFORM/BAS   VERSION 02/04/81
695 RUN"MAIN/BAS"
     :END
700 '*****************************************************
710 'GENERALIZED I/O SUBROUTINES FOR PROGRAM STARTERS
720 '//////////////////////
735 CLS
     :T$="NORTHERN HARDWOODS LABORATORY, US FOREST SERVICE"
     :GOSUB42000
736 T$="//////////////////////////////////////////////////////////"
     :GOSUB42000
     :PRINT
739 T$="MENU FOR:   MATRIX DATA TRANSFORMATION ROUTINE"
     :GOSUB42000
     :PRINT
740 IF TX=-1 THEN GOSUB 40000 ELSE 750
750 TX=1
     :PRINT"  1.  RETURN TO MAIN MENU          2.  GOTO BASIC
760 PRINT"  3.  READ A MATRIX FROM DISK      4.  WRITE A MATRIX TO
        DISK
770 PRINT"  5.  ENTER A MATRIX MANUALLY      6.  DISPLAY MATRIX ON
        VIDEO
780 PRINT TAB(2) "7.  PRINT MATRIX";TAB(34) "8.  ABSOLUTE VALUE"
790 PRINT TAB(2)"9.  INTEGER VALUE";TAB(33)"10.  EXPONENTIATION"
800 PRINT TAB(1)"11.  POWERS";TAB(33)"12.  SQUARE ROOT"
810 PRINT TAB(1)"13.  NATURAL LOGARITHM";TAB(33)"14.  BASE 10 LOG
      S"
900 PRINT
     :PRINT"SELECT ONE OF THE ABOVE --> ";
     :FL=-2
     :GOSUB15
     :AN=VAL(IN$)
903 IF AN>5 AND R=0 THEN 735
905 IF R=0 OR C=0 THEN 910 ELSE IF AN=1 OR AN=2 OR AN=3 OR AN=5 T
      HEN GOSUB 670
910 ON AN GOSUB 695,43000,130,220,340,510,620,10000,10040,10090,1
      0140,10200,10250,10300
920 GOTO 720
10000 FOR I=1 TO R
     :FOR J=1 TO J
10010 A(I,J)=ABS(A(I,J))
10020 NEXT J,I
10030 GOTO 10350
10040 ' TAKE INTEGER VALUES
10050 FOR I=1 TO R
     :FOR J=1 TOC
10060 A(I,J)=INT(A(I,J))
10070 NEXT J,I
10080 GOTO 10350
10090 '    EXPONENTIATE
10100 FOR I=1 TO R
     :FOR J=1 TO C
```

```
10110 A(I,J)=EXP(A(I,J))
10120 NEXT J,I
10130 GOTO 10350
10140 '     POWERS
10150 INPUT"PLEASE ENTER: POWER OF A[X";X
10160 FOR I=1 TO R
     :FOR J=1 TOC
10170 A(I,J)=A(I,J)[X
10180 NEXT J,I
10190 GOTO 10350
10200 '   SQUARE ROOT
10210 FOR I= 1TO R
     :FOR J=1 TO C
10220 A(I,J)=SQR(A(I,J))
10230 NEXT J,I
10240 GOTO 10350
10250 '   NATURAL LOGS
10260 FOR I=1 TO R
     :FOR J=1 TOC
10270 A(I,J)=LOG(A(I,J))
10280 NEXT J,I
10290 GOTO 10350
10300 '    BASE 10 LOGS
10310 FOR I=1 TO R
     :FOR J=1 TO C
10320 A(I,J)= LOG(A(I,J))/LOG(10)
10330 NEXT J,I
10350 RETURN
40000 DIM A(150,20),N$(20),B(150,20),SV(20)
40010 MV=-99.99
40020 RETURN
42000 CC=LEN(T$)
     :ZZ=INT(30-CC/2)
     :PRINT TAB(ZZ);T$
     :RETURN
     :'CENTERING ROUTINE
43000 END
```

APPENDIX VII. Source code listing for program ELEMOPS/BA

```
10 CLEAR 500
     :TX=-1
     :GOTO700
     :'ELEMOPS/BAS   VERSION 02/04/81
695 RUN"MAIN/BAS"
     :END
700 '*******************************************************
710 'GENERALIZED I/O SUBROUTINES FOR PROGRAM STARTERS
720 '////////////////////
735 CLS
     :T$="NORTHERN HARDWOODS LABORATORY, US FOREST SERVICE"
     :GOSUB42000
736 T$="///////////////////////////////////////////////////////"
     :GOSUB42000
     :PRINT
739 T$="MENU FOR:   ELEMENTARY ROW/COLUMN OPERATIONS ROUTINE"
     :GOSUB42000
     :PRINT
740 IF TX=-1 THEN GOSUB 40000 ELSE 750
750 TX=1
     :PRINT"  1.  RETURN TO MAIN MENU          2.  GOTO BASIC
760 PRINT"  3.  READ A MATRIX FROM DISK      4.  WRITE A MATRIX TO
       DISK
770 PRINT"  5.  ENTER A MATRIX MANUALLY      6.  DISPLAY MATRIX ON
       VIDEO
780 PRINT TAB(2) "7.  PRINT MATRIX";TAB(34) "8.  FLIP TWO ROWS"
790 PRINT TAB(2)"9.  FLIP TWO COLUMNS";TAB(33)"10.  ROW * SCALAR"

800 PRINT TAB(1)"11.  COLUMN * SCALAR";TAB(33)"12.  ROW + SCALAR
      * ROW"
810 PRINT TAB(1)"13.  COL + SCALAR * COL";TAB(33)"14.  (ROW OR CO
      L) / ELEMENT"
900 PRINT
     :PRINT"SELECT ONE OF THE ABOVE --> ";
     :FL=-2
     :GOSUB15
     :AN=VAL(IN$)
     :CLS
903 IF AN>5 AND R=0 THEN 735
905 IF R=0 OR C=0 THEN 910 ELSE IF AN=1 OR AN=2 OR AN=3 OR AN=5 T
      HEN GOSUB 670
910 ON AN GOSUB 695,43000,130,220,340,510,620,1580,1660,1740,1800
      ,1860,1940,2100
920 GOTO 720
1580 '   INTERCHANGE TWO ROWS
1600 INPUT"PLEASE ENTER: ROWS TO BE INTERCHANGED (X,Y)";F,T
1610 FOR J=1 TO C
1620 TEMP=A(T,J)
     :A(T,J)=A(F,J)
     :A(F,J)=TEMP
1630 NEXT J
1640 GOTO 2000
1650 END
1660 '      INTERCHANGE ANY TWO COLUMNS
1680 INPUT"PLEASE ENTER: COLS TO BE INTERCHANGED (X,Y)";F,T
```

```
1690 FOR I=1 TO R
1700 TEMP=A(I,T)
     :A(I,T)=A(I,F)
     :A(I,F)=TEMP
1710 NEXT I
1715 TR$=N$(T)
     :N$(T)=N$(F)
     :N$(F)=TR$
1720 GOTO 2000
1730 END
1740 '       MULTIPLY A ROW TIMES A CONSTANT
1760 INPUT"PLEASE ENTER: ROW AND CONSTANT MULTIPLIER (R,K)";RR,K
1770 FOR J=1 TO C
     :A(RR,J)=K*A(RR,J)
     :NEXT J
1780 GOTO 2000
1790 END
1800 '      MULTIPLY A COLUMN BY A CONSTANT
1820 INPUT"PLEASE ENTER: COL AND CONSTANT MULTIPLIER (C,K)";CC,K
1830 FOR I=1 TO R
     :A(I,CC)=K*A(I,CC)
     :NEXT I
1840 GOTO 2000
1850 END
1860 '       ADDITION OF A ROW MULTIPLIED BY A K TO ANOTHER
1880 INPUT"PLEASE ENTER: R2 + K * R1   (R2,K,R1)";R2,K,R1
1890 FOR J=1 TO C
1900 A(R2,J)=A(R2,J)+K*A(R1,J)
1910 NEXT J
1920 GOTO 2000
1930 END
1940 '     ADDITION OF A COL MULTIPLIED BY A K TO ANOTHER
1960 INPUT"PLEASE ENTER: C2 + K * C1 (C2,K,C1)";C2,K,C1
1970 FOR I=1 TO R
1980 A(I,C2)=A(I,C2)+K*A(I,C1)
1990 NEXT I
2000 RETURN
2010 END
2100 REM*****************************************
2110 REM           ROUTINE TO DIVIDE A ROW/COL BY AN ELEMENT
2120 REM
2130 RR=1
     :INPUT"DO YOU WISH TO OPERATE ON A ROW (R) OR A COLUMN (C)";A$
2140 IF A$="C" THEN RR=2
2150 INPUT"PLEASE ENTER: WHICH ROW/COL DO YOU WISH TO OPERATE ON"
      ;K
2160 IF RR=2 GOTO  2190
2170 IF K>0 AND K<=R GOTO 2210
2180 PRINT"SELECTION ";K;"IS NOT A ROW. PLEASE TRY AGAIN."
     :PRINT
     :GOTO 2150
2190 IF K>0 AND K<=C GOTO  2210
2200 PRINT"SELECTION ";K;"IS NOT A COLUMN. PLEASE TRY AGAIN."
     :PRINT
     :GOTO 2150
```

```
2210 INPUT"GIVE COORDINATES OF ELEMENT THAT WILL BE THE DIVISOR (
      I,J)";A,B
2220 IF A>0 AND B>0 AND A<=R AND B<=C GOTO 2250
2230 PRINT"THE MATRIX HAS ";R;" ROWS AND ";C;" COLUMNS."
2240 PRINT"PLEASE SELECT I AND J WITHIN THESE BOUNDS."
     :PRINT
     :GOTO 2210
2250 TE=A(A,B)
     :IF RR=2 GOTO 2280
2260 FOR I=1 TO C
     :A(K,I)=A(K,I)/TE
     :NEXT I
2270 RETURN
2280 FOR I=1 TO R
     :A(I,K)=A(I,K)/TE
     :NEXT I
2290 RETURN
2300 END
10000 FOR II=1 TO 1000
     :NEXT II
     :RETURN
40000 DIM A(150,20),N$(20),B(150,20),NB$(20)
40015 MV=-99.99
40020 RETURN
42000 CC=LEN(T$)
     :ZZ=INT(30-CC/2)
     :PRINT TAB(ZZ);T$
     :RETURN
     :'CENTERING ROUTINE
43000 END
```

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The Numerical Information Manipulation System extends the versatility provided by word processing systems for textural data manipulation to mathematical or statistical data in numeric matrix form. Numeric data, stored and processed in the matrix form, may be manipulated in a wide variety of ways. The system allows operations on single elements, entire rows, or columns, or on entire data matrices. Data elements may be transformed by logarithmic, power, exponential, and other operations. When data sets are treated as a single matrix unit, they may be added, subtracted, multiplied, inverted, and separated or merged in any desired configuration.

KEY WORDS: Data analysis, TRS-80, data processing, matrix operations.

United States
Department of
Agriculture

Forest
Service

North Central
Forest Experiment
Station

General Technical
Report NC-85

The Microcomputer Scientific Software Series 2

General Linear Model - Regression

Harold M. Rauscher

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THE MICROCOMPUTER SCIENTIFIC SOFTWARE SERIES 2: GENERAL LINEAR MODEL—REGRESSION

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Grand Rapids, Minnesota

GENERAL INFORMATION

Identification

Name: General Linear Model–Regression (GLMR)

Location North Central Forest Exp. Station
1831 Highway 169 East
Grand Rapids, MN 55744

Language: Microsoft BASIC

Computer: Radio Shack TRS-80 Microcomputer[1]

Summary

General

The general linear model regression (GLMR) program provides the microcomputer user with a sophisticated regression analysis capability. GLMR is a member of the SPS family of programs (Buhyoff *et al.* 1980). It provides the utmost generality regarding choice of models. The output provides a regression ANOVA table, estimators of the regression model coefficients, their confidence intervals, confidence intervals around the predicted Y-values, residuals for plotting, a check for multicollinearity, a check for autocorrelation, and the scaled regression coefficients. A plotting routine is part of the regression program to facilitate quick plotting of residuals.

Documentation

This manual will explain the operation of GLMR, detail how the program functions in enough depth to allow a knowledgeable user to implement improvements and extensions, and present the complete source code listings.

Objectives

In this paper I have two objectives:

(a) Provide small computer users with a flexible and general purpose regression analysis package.

(b) Provide user instructions in enough detail to allow implementation of extensions to the basic system.

Assumptions

I assume that the users of GLMR are also programmers. In my opinion, the opportunity cost of owning a small computer system without being able to program it is too high. Consequently, this document is aimed at users who understand the operating environment of their small computer, can program their small computer in its resident BASIC dialect, and have some understanding of the differences between the many dialects of BASIC in use.

Furthermore, I assume that users have enough statistical knowledge to intelligently use regression analysis. This manual does not teach regression analysis. The theoretical basis for regression analysis is presented in some depth to allow the informed reader to judge the mathematical approach used as the basis of this program.

---

[1] *Mention of trade names does not constitute endorsement of the products by the USDA Forest Service.*

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Quick Reference Guide

Input requirements

There are two input requirements: an m (number of observations) by 1 matrix containing the observations on the dependent variable and an m by n (number of variables) matrix containing the corresponding independent data. When an intercept term is required in the regression equation, the first v
iable of the independent data matrix must be a c
umn of 1's. When no intercept term is desired, i
the line is forced through the origin, the column
1's must be absent.

Regression analysis options

The following 10 regression analysis options a
available:

(a) ANOVA table with regression coefficients,
(b) test for homogeneity of variances,
(c) confidence intervals for the coefficients,
(d) confidence intervals for the estimates of t
dependent variable,
(e) plotting of residuals,
(f) check for multicollinearity,
(g) store the (X'X) inverse matrix on disk,
(h) check for autocorrelation,
(i) scaled regression coefficients, and
(j) test for equality of regression coefficients.

APPLICATION
Introduction

This section of the guide will teach how to proper
use GLMR. Each option in the system will be pr
sented, discussed, and illustrated by example.

For the purposes of linear regression, a model
linear in the parameters for any function of the i
dependent variable as long as these functions do n
involve the coefficients b_i. The general form of a li
ear model is (Mather 1976)):

$$Y = b_0 + b_1 A_1 + \ldots + b_k A_k \qquad ($$

$$\text{where: } A_k = f(x_1, x_2, \ldots, x_k)$$

This program requires an input Y, the m by 1 matr
of observations on the dependent variable. Due
memory size constraints, the program is dime
sioned to accept no more than 200 observations. T
X matrix must be an m by n matrix in which t
columns of X are the observations on the indepe
dent variable(s). Missing values, coded -99.99, a
not allowed in matrices Y and X. The program
constrained to accept no more than 10 independe
variables when no intercept term (b_0) is in the mod
When b_0 is used, only 9 independent variables a
permitted. All dimensions are in line number 400
and may be readily changed to meet changing nee
consistent with the available maximum memory

hardware. For example, a problem with only 50 ervations could use up to 40 independent varias in the model equation. If an intercept term (b_0) n the model, then the first column of X must tain all 1's. How the values of the independent iables are computed is irrelevant to the program. s allows maximum design flexibility for the anst.

o illustrate the use of this program, I will follow example from the widely available text on regres1 analysis by Draper and Smith (1966, p. 362) ble 1). Load the disk with the programs on the k drive which must have the operating system sent (drive 0) and a formatted data diskette with operating system present on drive 1. Run program LR/BAS". The menu of choices wil present itself . 1). Select number 5 to enter matrix Y from the board. You will be asked for the number of rows in the matrix and the number of columns (1) to er <25,1>. Next you will be asked to give the t column a name, enter <Y>. After the 25th elent has ben entered, you are automatically rened to the menu.

elect number 6 to display the Y matrix. Notice t only 13 of the 25 columns of Y are displayed at time. Pressing the down arrow on the keyboard plays the next "page" of data. Pressing the up ow returns the first page to the screen. When a trix has more than 4 columns, only four columns l be displayed on any given "page". The left and right arrows move the "page" across the desired tions of the matrix. To return to the menu press <CLEAR> button. To save the matrix Y for use h the regression program it is necessary to select nber 4. You will be asked to name matrix Y. It is t not to label it "Y" because the program uses the nes, Y, X, B, and XPXI to store intermediate rets. You are then asked to specify the disk on which want to store the matrix. Using the TRS-80, this should always be a disk other disk drive 0, the drive that contains the operating system. This practice ensures sufficient disk storage for the intermediate matrices. Enter the matrix X into memory the same way and save it using a name other than X.

Table 1.—*Example dependent variable (Y) and independent variables (X) from Draper and Smith (1966) p. 362*

	Dependent variable	Independent variables		
COL:	Y	X0	X8	X6
R 1 :	10.98	1	35.3	20
R 2 :	11.13	1	29.7	20
R 3 :	12.51	1	30.8	23
R 4 :	8.4	1	58.8	20
R 5 :	9.27	1	61.4	21
R 6 :	8.73	1	71.3	22
R 7 :	6.36	1	74.4	11
R 8 :	8.5	1	76.7	23
R 9 :	7.82	1	70.7	21
R 10:	9.14	1	57.5	20
R 11:	8.24	1	46.4	20
R 12:	12.19	1	28.9	21
R 13:	11.88	1	28.1	21
R 14:	9.57	1	39.1	19
R 15:	10.94	1	46.8	23
R 16:	9.58	1	48.5	20
R 17:	10.09	1	59.3	22
R 18:	8.11	1	70	22
R 19:	6.84	1	70	11
R 20:	8.88	1	74.5	23
R 21:	7.68	1	72.1	20
R 22:	8.47	1	58.1	21
R 23:	8.86	1	44.6	20
R 24:	10.36	1	33.4	20
R 25:	11.08	1	28.6	22

Once Y and X are stored on disk 1, select number 8. You are asked to enter the name of your Y matrix and of your X matrix. These two matrices are read into the active memory and the program commences. After some period of waiting, you will be asked to input the number of significant figures in the raw

```
MENU FOR: GENERAL LINEAR REGRESSION ANALYSIS
                    SYSTEM

RETURN TO MAIN MENU                 2. GOTO BASIC
READ A MATRIX FROM DISK             4. WRITE A MATRIX TO DISK
ENTER A MATRIX MANUALLY             6. DISPLAY MATRIX ON VIDEO
PRINT MATRIX                        8. GENERAL LINEAR REGRESSION
BARTLETT'S TEST FOR HOMOGENEITY
OF VARIANCES

LECT ONE OF THE ABOVE —>..
```

ure 1.—*Menu of options, program GLR/BAS of the GLMR system.*

data. The presence of errors in the data and in the computational processes prevent the program from detecting when a singular value, computed as small but not zero, is in fact zero. If the matrix is less than full rank, a warning is issued (see discussion of multicollinearity below). You will be asked whether or not to include the mean in the ANOVA table. Including the mean displays the amount of the total sums of squares that has been accounted for by the mean. This sum of squares is not evident in the "usual" ANOVA table in which the mean is not included.

The ANOVA display presents the "usual" results (fig. 2). The estimates of the regression coefficients are given at the bottom of the list of output. The ANOVA table will persist until you depress the <SPACE> bar. You are queried about the mean again and a positive response will display the ANOVA table with the mean included (fig. 3). Finally, you are asked whether you want to continue the analysis by computing confidence intervals or performing error analysis. If the answer to the above question is yes, the pertinent matrices are saved on disk 1 and the second part of the program is moved into memory and activated.

The menu for part II will automatically a
(fig. 4). The Y matrix at this point shows fou
umns—the original Y values, the estimated
values, the residuals (EHAT), and the norm
residuals (ZHAT) (table 2). The confidence int
of the coefficients will result if selection num
is chosen (table 3). The test for $b_i = 0$ is easilly
by seeing whther or not 0 falls within the confi
limits of b_i. The standard deviation, which is n
to test the equality of regression coeffficients, i
sented with this option. Choosing selection nu
9 produces the confidence intervals around th
dicted Y values (fig. 5). If you will want to pl
confidence band around the regression line, sa
augmented Y matrix when queried.

Some indicators in evaluating multicollin
are displayed upon choosing selection number 1
6). The condition number of X can be used
index of collinearity (Forsythe *et al.* 1977). If co
is close to 1, the columns of X are very indepe
If cond(X) is large, the colums of X are near
pendent. A matrix A may be considered to be
singular than a matrix B if cond(A) > cond(B
collinearity number is that condition numbe

```
                REGRESSION ANALYSIS OF VARIANCE TABLE
SOURCE              DF         SS            MS             F          PROBABIL
-------------------------------------------------------------------------------
REG                  2       54.1858       27.0929        61.9027         0.0000
ERROR               22        9.62872        .437669
-------------------------------------------------------------------------------
TOTAL               24       63.8145
MEAN OF RESPONSE VARIABLE Y = 9.424
STD. DEV. OF ERROR = .661566 C.V. of Y = 7.0
MULTIPLE CORRELATION COEFFICIENT (R**2) = .849115
REGRESSION COEFFICIENTS
B O = 9.12692   B 1 = -.0723934   B 2 = .202815
```

Figure 2.—*ANOVA display for the example problem without a line for the "MEAN".*

```
                REGRESSION ANALYSIS OF VARIANCE TABLE
SOURCE              DF         SS            MS             F          PROBABIL
-------------------------------------------------------------------------------
MEAN                 1      2220.3        2220.3         5073             0.0000
REG.                 2        54.1858       27.0929        61.9027        0.0000
ERROR               22         9.62872        .437669
-------------------------------------------------------------------------------
TOTAL               25      2284.11
MEAN OF RESPONSE VARIABLE Y = 9.424
STD. DEV. OF ERROR = .661566  C.V. of Y = 7.0
MULTIPLE CORRELATION COEFFICIENT (R**2) = .849115
REGRESSION COEFFICIENTS
B O = 9.12692   B 1 = -.0723934   B 2 = .202815
```

Figure 3.—*ANOVA display for the example problem with a line for the "MEAN".*

```
MENU FOR: GENERAL LINEAR REGRESSION ANALYSIS
                    SYSTEM
ART II. CONFIDENCE INTERVALS AND ERROR ANALYSIS
RETURN TO MAIN MENU                    2. GOTO BASIC
READ A MATRIX FROM DISK                4. WRITE A MATRIX TO DISK
ENTER A MATRIX MANUALLY                6. DISPLAY MATRIX ON VIDEO
PRINT MATRIX                           8. CONFIDENCE INTERVALS FOR B
CONFIDENCE INTERVALS FOR YHAT         10. PLOT RESIDUALS
MULTICOLLINEARITY CHECK               12. HETEROSCEDASTICITY CHECK
AUTOCORRELATION CHECK                 14. SCALED B
EQUALITY OF REG. LINES

ECT ONE OF THE ABOVE —>..
```

re 4.—*Menu of options program GLRI/BAS of the GLMR system.*

ld cause the matrix X to be rank deficient. If
original input to the number of significant dig-
n the data produces a less than full rank matrix,
the program again with more digits specified as
ificant. If the matrix is then of full rank, then
need to be wary in the use of the coefficients.
estimates of B will still be unbiased but a large
dard error will result indicating that the prob-
ity of an individual b_i that is far from the true
ulation b_i is increased (Mather 1976). This is not
cal for predictive uses but would be unacceptable
explanatory purposes. One solution to problems
ulticollinearity is ridge regression.

le 2.—*The "Y" matrix for the example problem*

Data set name —> Y			
Y	YHAT	EHAT	ZHAT
10.98	10.6277	.352269	.532478
11.13	11.0331	.0968657	.146419
12.51	11.5619	.948053	1.43305
8.4	8.92649	-.526486	-.795819
9.27	8.94108	.328921	.497186
8.73	8.4272	.302802	.457705
6.36	5.97181	.388187	.586771
8.5	8.23909	.260911	.394384
7.82	8.26782	-.44782	-.676909
9.14	9.0206	.119403	.180485
8.24	9.82416	-1.58416	-2.39457
12.19	11.2939	.896136	1.35457
11.88	11.3518	.528221	.798441
9.57	10.1498	-.579822	-.876439
10.94	10.4037	.536348	.810726
9.58	9.67214	-.0921383	-.139273
10.09	9.29592	.794081	1.20031
8.11	8.52131	-.41131	-.621723
6.83	6.29034	.539657	.815728
8.88	8.39836	.481646	.728039
7.68	7.96365	-.283653	-.428761
8.47	9.17998	-.709977	-1.07318
8.86	9.95447	-1.09447	-1.65437
10.36	10.7653	-.405279	-.612606
11.08	11.5184	-.438397	.662667

Option number 13 provides the Durbin-Watson statistic to test autocorrelation. In the example, this statistic has the value of 2.2. The evaluation of this statistic is presented by Durbin and Watson (1950, 1951, 1971). If significant autocorrelation is shown, three possibiities exist (Mather 1976). (1) The functional form of the model is incorrect, change it. (2) Some explanators are missing, plot the residuals against some possible candidates. If a relationship is found, include the new predictors into the model. (3) The data contain a true autoregressive structure.

Option number 14 activates the routine that calculates the standardized coefficients. These scaled coefficients allow evaluation of relative importance. The larger the scaled coefficient, the more that independent variable contributed to explaining the total variation.

Option number 12, check for heteroscedasticity, is currently not activated. Option number 10, plotting residuals, allows visual analysis for heteroscedasticity as recommended by Draper and Smith (1966). At this point, the Y matrix is augmented with the columns of the X matrix and one column for the observation numbers (table 4). If the augmented matrix exceeds 10 columns, an error will occur. Change the dimension statement in line 40000 to increase the number of columns as required by the problem.

Table 3.—*Confidence interval and standard deviation of the regression coefficient for the example problem*

	Coefficient	Upper level	Lower level	Stand. dev.
B 0	9.12692	11.4159	6.83794	1.1028
B 1	-.0723934	-.0557898	-.088997	7.99942E-03
B 2	.202815	.29781	.10782	.0457676

CONFIDENCE INTERVALS FOR PREDICTED Y VALUES T-VALUE FOR 95 TWO-SIDED CONFIDENCE INTERVAL = 2.0756 DF = 22

```
YHAT        UPPER      LOWER     STAND.
              CI         CI        ERR.
10.6277     11.0292    10.2262   .193436
11.0331     11.5065    10.5597   .2281
11.5619     12.047     11.0768   .233737
 8.92649     9.21899    8.634    .140921
 8.94108     9.26728    8.61488  .15716
 8.4272      8.89789    7.95651  .226775
 5.97181     6.89029    5.05333  .442512
 8.23909     8.82925    7.64893  .284334
 8.26782     8.69214    7.8435   .204434
 9.0206      9.30658    8.73462  .13778
 9.82416    10.12       9.52832  .142535
11.2939     11.7667    10.8211   .227802
11.3518     11.8353    10.8683   .232955
10.1498     10.5379     9.7617   .18698
10.4037     10.7817    10.0258   .182092
 9.67214     9.95714    9.38714  .137312
 9.29592     9.64742    8.94442  .169349
 8.52131     8.9764     8.06623  .219254
 6.29034     7.19751    5.38317  .437063
 8.39836     8.96083    7.83589  .270993
 7.96365     8.38516    7.54214  .203078
 9.17998     9.48286    8.8771   .145926
 9.95447    10.2625     9.64648  .148385
10.7653     11.1903    10.3403   .204757
11.5184     12.0024    11.0344   .233167
```

Figure 5.—*Confidence intervals around the predicted Y values of the example problem as viewed on the video display.*

The Y matrix is on disk, so you have lost nothing. If the variances of the residuals are not equal, then the least squares estimators B will not be of minimum variance although they will still be unbiased. Variances will be heterosedastic if they increase or decrease with any of the independent variables. Because the predicted values of Y are linear functions of the independent variables, the residuals, EHAT, can also be plotted against Y and the scatter observed for trends. If a functional relationship between the residuals and Y's can be found then weighted least sqares is a solution.

CHECK FOR MULTICOLLINEARITY

```
RANK (X) = 3 X HAS FULL RANK
MAXIMUM SINGULAR VALUE (X) = 292.5
MINIMUM SINGULAR VALUE (X) = .59945
CONDITION NUMBER FOR (X) = 488.051
COLLINEARITY NUMBER FOR (X) = 1E+

IF CONDITION NUMBER IS CLOSE TO 1,
   INDEPENDENT (NONSINGULAR).
IF CONDITION NUMBER IS INFINITE, X =
   PENDENT (SINGULAR).
IF CONDITION NUMBER CLOSE TO CO
   NEARITY NUMBER, X = NEARLY DE
   DENT (SINGULAR)
```

Figure 6.—*Multicollinearity indicators for th*
ample problem.

Selection of option number 10 activates the
ting part of the program. Use option number
number 6 to review the Y matrix. You will s
original Y vector, the predicted Y, the error
normalized errors and if you chose to save the
confidence intervals around the predicted Y.
dition, the columns of the X matrix are now co
of the Y matrix as well (table 4). Select option
ber 10. Answer the first question with 1 for dis
enter the name of the data matrix as Y. You are
the choice of viewing Y and reviewing the na
the variables in Y. Choose variable number 9
x-axis designate and the residuals, EHAT, va
number 3, as the Y-axis designate. Decline th
ing option because the X-axis is in ascending
already and the graphing status menu is disp
(fig. 7). The X and Y axis designates are pre
along with their ranges. The ranges can be ch
by selecting either number 3 or number 4. Sele
number 5 and number 6 allow manipulation
tical and horizontal control lines on the plot o
Options number 7 through number 9 allow
nation of title and labeling of the axes. Option
ber 10 executes the plotting routine (fig. 8). Th
of the lineplotter output is patterned after
(1979).

This regression system can also be used to t
homogeneity of variances and for the equa
regression coefficients. Option number 9 of th
regression menu (fig. 1) is used to enter the t
homogeneity of variance. Using the example o
370 of Sokal and Rohlf (1969), the program re
as input the variances and their degrees of fr

ble 4.—*Augmented Y matrix for plotting*

L:	Y	YHAT	EHAT	ZHAT	Y-UPPER	Y-LOWER	X1	X2	OBS
:	10.98	10.6277	0.352269	0.532478	11.0292	10.2262	35.3	20	1
:	11.13	11.0331	.0968657	.146419	11.5065	10.5597	29.7	20	2
:	12.51	11.5619	.948053	1.43305	12.047	11.0768	30.8	23	3
:	8.4	8.92649	-.526486	-.795819	9.21899	8.634	58.8	20	4
:	9.27	8.94108	.328921	.497186	9.26728	8.61488	61.4	21	5
:	8.73	8.4272	.302802	.457705	8.89789	7.95651	71.3	22	6
:	6.36	5.97181	.388187	.586771	6.89029	5.05333	74.4	11	7
:	8.5	8.23909	.260911	.394384	8.82925	7.64893	76.7	23	8
:	7.82	8.26782	-.44782	-.676909	8.69214	7.8435	70.7	21	9
0:	9.14	9.0206	.119403	.180485	9.30658	8.73462	57.5	20	10
1:	8.24	9.82416	-1.58416	-2.39457	10.12	9.52832	46.4	20	11
2:	12.19	11.2939	.896136	1.35457	11.7667	10.8211	28.9	21	12
3:	11.88	11.3518	.528221	.798441	11.8353	10.8683	28.1	21	13
4:	9.57	10.1498	-.579822	-.876439	10.5379	9.7617	39.1	19	14
5:	10.94	10.4037	.536348	.810726	10.7817	10.0258	46.8	23	15
6:	9.58	9.67214	-.0921383	-.139273	9.95714	9.38714	48.5	20	16
7:	10.09	9.29592	.794081	1.20031	9.64742	8.94442	59.3	22	17
8:	8.11	8.52131	-.41131	-.621723	8.9764	8.06623	70	22	18
9:	6.83	6.29034	.539657	.815728	7.19751	5.38317	70	11	19
0:	8.88	8.39836	.481646	.728039	8.96083	7.83589	74.5	23	20
1:	7.68	7.96365	-.283653	-.428761	8.38516	7.54214	72.1	20	21
2:	8.47	9.17998	-.709977	-1.07318	9.48286	8.8771	58.1	21	22
3:	8.86	9.95447	-1.09447	-1.65437	10.2625	9.64648	44.6	20	23
4:	10.36	10.7653	-.405279	-.612606	11.1903	10.3403	33.4	20	24
5:	11.08	11.5184	-.438397	-.662667	12.0024	11.0344	28.6	22	25

```
. X-VARIABLE = VAR. #9
. Y-VARIABLE = VAR. #3
. RANGE OF X-VARIABLE —> 1 TO 25
. RANGE OF Y-VARIABLE —> -2 TO 2
. VERTICAL CONTROL LINE STATUS —> OFF
. HORIZONTAL CONTROL LINE STATUS    ON
. TITLE OF GRAPH —> PLOT OF EXAMPLE
  PROBLEM FROM DRAPER & SMITH P. 364
. X-AXIS LABEL —> X-AXIS: OBSERVATION
  NUMBER
. Y-AXIS   LABEL   —>   Y-AXIS:   RESI-
   DUALS   Y–YHAT
. EXECUTE THE GRAPHING ROUTINE
. GET ANOTHER MATRIX
. REGRESSION PART II
. DISPLAY MATRIX
. PRINT DATA MATRIX

LECT STATUS CHANGES OR CONTINUATION
>..
```

gure 7.—*Graphing status menu for the example problem.*

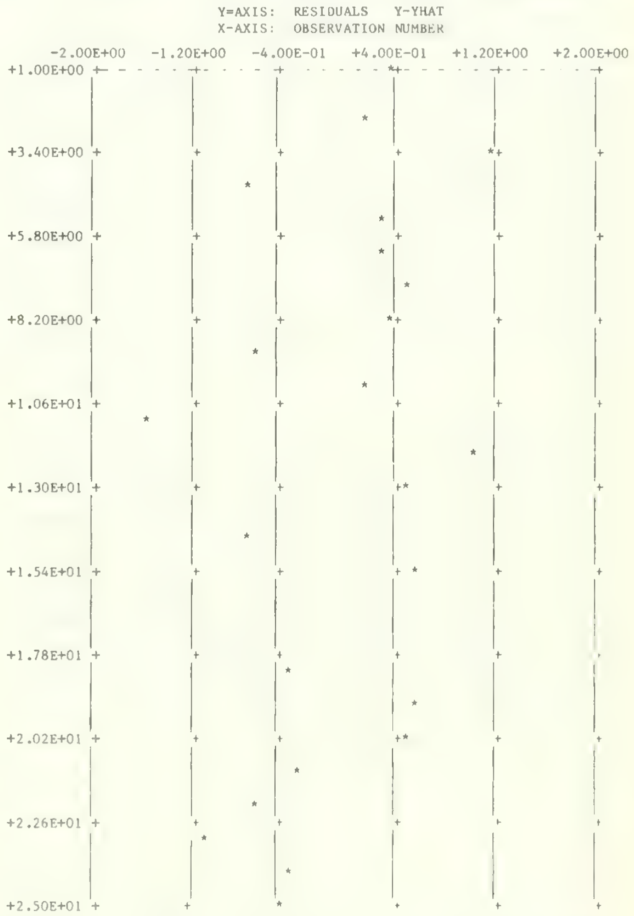

Figure 8.—*Plot of residuals for the example problem from Draper & Smith (1966).*

```
HOW MANY EQUATIONS ARE TO BE COMPARED? —> 2.
ARE THE VARIANCES ASSUMED HOMOGENEOUS <0> OR HETEROGENEOUS <E>?

PLEASE ENTER THE REQUESTED INFORMATION FOR EACH EQUATION.

EQUATION #1
VALUE OF B COEFFICIENT —> 3.238
STANDARD DEVIATION OF B —> 1.307
ERROR SUM OF SQUARES —> 21521
ERROR DEGREES OF FREEDOM —> 9

EQUATION #2
VALUE OF B COEFFICIENT —> 2.52
STANDARD DEVIATION OF B —> 0.284
ERROR SUM OF SQUARES —> 26874
ERROR DEGREES OF FREEDOM—> 17

WISH TO REVIEW THE INPUT? (Y/N) —> Y.

COL:          B        STAND.DEV.     ERROR SS    ERROR DF
-----------------------------------------------------------
R 1:        3.238        1.307         21521          9
R 2:        2.52          .284         26874         17

CONTINUE <C> OR REDO INPUT<R>? —> C.
```

Figure 9.—*Procedure for testing equality of regression coefficients.*

The values of the variances must be greater than or equal to 1 because a logarithmic transformation is used in the calculation. This program allows the user to multiply all variances by an appropriate values. Be warned that Bartlett's test is sensitive to departures from non-normality in the data. Hence, a significant qui-squared value may indicate non-normality rather than heteroscedasticity (Sokal and Rohlf 1969).

The test for equality of regression coefficients is entered from menu part II (fig. 4). Data requirements are: the values of the coefficients, their standard deviation, the error sum of squares for each regression equation, the error degrees of freedom, and whether the error variances are assumed to be homogeneous or heterogeneous. The example of this procedure comes from Snedecor and Cochran (1967, p. 435). Follow the procedure in figures 9 and 10. The computational details are presented in the "Equality of Regression Coefficients—Theory" section.

(A)

```
RESULTS OF THE TEST FOR EQUALITY OF REGRESSIO
COEFFICIENTS.

WEIGHTED AVERAGED B = 2.56786
SUM OF SQUARE FOR COMBINED B'S = 673.531
NUMERATOR DEGREES OF FREEDOM = 1
MEAN SQUARE FOR B'S = 673.531
COMBINED ERROR SUM OF SQUARES = 48395
DENOMINATOR DEGREES OF FREEDOM = 26
COMBINED ERROR MEAN SQUARE = 1861.35
THE CALCULATED F-VALUE = 361852
THE PROBABILITY OF REJECTING THE NULL HYPOTH
.4407
```

(B)

```
RESULTS OF THE TEST FOR EQUALITY OF REGRESSIO
COEFFICIENTS

WEIGHTED AVERAGED B = 2.64824
SUM OF SQUARES FOR COMBINED B'S = 653.573
NUMERATOR DEGREES OF FREEDOM = 1
MEAN SQUARE FOR B's = 653.573
COMBINED ERROR SUM OF SQUARES = 48395
DENOMINATOR DEGREES OF FREEDOM = 24
COMBINED ERROR MEAN SQUARE = 2016.46
THE CALCULATED F-VALUE = .324119
THE PROBABILITY OF REJECTING THE NULL HYPOTH
.4192
```

Figure 10.—*Results of test for equality of regr coefficients for the example problem: (A) geneous case (B) Heterogeneous case.*

PROCEDURES AND REQUIREMENTS

System Characteristics

Program GLMR is written in BASIC for the TRS-
microcomputer. The computer should have a min-
m of 48K of user defineable random access mem-
(RAM), two disk drives, and a lineprinter. Highly
patible versions of BASIC are available for most
rocomputer systems. It is anticipated that, with
inimum of effort, this program can be converted
xecute on any computer system that can use some
lect of the BASIC language.

Performance

A problem with 25 observations and 2 indepen-
t variables plus intercept takes approximately 2
utes to solve. One with 13 observations and 5
ependent variables plus intercept takes approx-
tely 3 minutes to solve.

Data Compatibility

Program GLMR is compatible with the data stan-
d used by the SPS system (Buhyoff *et al.* 1980).
e numerical data of interest are built into a ma-
, A_{ij}, where i = number of observations and j =
nber of variables. Each data set has three data
s automatically defined for it. If "TEST", "TESTN",
"TESTL" will be automatically created or up-
ed every time "TEST" is saved to disk. File
STM" contains the matrix A_{ij}. I have found that
a file manipulations are greatly simplified by us-
this three file organization.

Matrix A(R,C) is used to transfer data to and from
k, R and C are the row/column dimensions, and
C) is used to store names of the variables. The
ut matrices required by this program may be cre-
d by GLM or by the numerical information ma-
ulation system (NIMS) reported by Rauscher
33). The output data matrices generated by GLMR
compatible with all of the above referenced pro-
ms.

Availability

Owners of Model I TRS-80 single sided, single den-
, 5-1/4" disk based systems who desire a machine
dable copy of this program must send a blank
kette to the author.

Regression Theory

GLMR is based upon the theory of general linear models as presented by Searle (1971). The problem in linear regression is to find a solution to:

$$Y = X B + E \qquad (2)$$

where:

Y = the m by 1 matrix of observations on the dependent variable
X = the m by n matrix of observations on the independent variables
B = the n vector of parameters
E = the n vector of errors
$r(X)$ = n; X has full rank

subject to the constraint that the sum of the squares of the errors is minimized. The solution to (2) is:

$$\hat{B} = (X'X)^{-1} X'Y \qquad (3)$$

where:

$\hat{B}$ = the n vector of estimates of parameters
X' = transpose of X
$(X'X)^{-1}$ = inverse of X'X

The most reliable method for computing the coefficients ($\hat{B}$) for the general least-squares problem is known as singular value decomposition (Forsythe *et al.* 1977). Although other algorithms may require less computer time and storage, they are less effective in dealing with errors in the data, runoff errors, and linear dependence of X. The singular value decomposition algorithm of Golub and Reinsch (1970) was used as the basis for solving the least squares problem in this program. A singular value decomposition computes a factorization of the form:

$$X = U S V' \qquad (4)$$

where:

S = m by n diagonal matrix of singular values if $S_{ii} < q$ then $S_{ii} = 0$
S_{ii} = ith singular value
q = a tolerance value based on the precision of the data in the X matrix
U = an m by m orthogonal matrix
V = an n by n orthogonal matrix.

and

$$\hat{B} = (X'X)^{-1} X' Y = V S^{+} U'Y \text{ where } S^{+}_{ii} = 1/S_{ii} \qquad (5)$$

(Forsythe *et al.* 1977)

$$(X'X)^{-1} = V (S^{+})^{2} V' \text{ (Nash 1979)} \qquad (6)$$

Using these results as the basis, the regression estimators, variances, and sums of squares can be computed as outlined in Searle (1971):

$$\widehat{E(Y)} = Y = X B \qquad (7)$$

where:

$$\widehat{E(Y)} = Y = \text{estimates of } Y$$

$$E'E = \text{error sum of squares} = SSE \qquad (8)$$

$$(\text{sigma})^2 = SSE/(m\text{-}r(X)) \qquad (9)$$

where:

$(\text{sigma})^2$ = residual error estimate of variance
m = number of observations
$r(X)$ = rank of X

$$SST = Y'Y = \text{total sum of squares} \qquad (10)$$

$$SSR = SST - SSE = \text{sum of squares due to regression} \qquad (11)$$

$$SSM = m * Y^2 = \text{correction term for the mean} \qquad (12)$$

where:

$\hat{Y}$ = mean of Y

$$SSRm = SSR - SSM = \text{regression sum of squares corrected for the mean} \qquad (13)$$

$$SSTm = SST - SSM = \text{corrected sum of squares of dependent variable } Y \qquad (14)$$

$$R^2 = SSR/SST \text{ no intercept model } b_0 \qquad (15)$$
$$= SSRm/SSTm \text{ intercept model } b_0 <> 0$$

where:

R^2 = multiple correlation coefficient

$$\text{var}(\hat{B}) = (X'X)^{-1} = V(S^+)^2\, V' \qquad (16)$$

where:

$\text{var}(\hat{B})$ = variance of parameter estimators

$$\text{var}(\hat{Y}) = X\,(X'X)^{-1}\,X' = X\,V\,S^+\,U' \qquad (17)$$

where:

$\text{var}(\hat{Y})$ = variance of estimates of Y.

Regression Assumptions

A linear regression analysis may be used for predicting values of the dependent variable or as part of the process of scientific explanation of the variation in the dependent variable as accounted for in terms of the independent variables (Mather 1976). The assumptions needed for both of these purposes of regression were discussed in detail by Mather (1976) and they are summarized here.

1. The mean of the residuals is zero. This assumption implies that no important explanatory variable has been omitted in the model and that the chosen independent variables represent the major controls on the variability of the dependent variable.
2. The variance of the residuals and the varia
the dependent variable are constant at eacl
of the independent variable. This is the as
tion of homoscedasticity.
3. The independent variables are nonrando
are measured without error.
4. The independent variables are not multicol
that is, they are not perfectly linearly rela
5. The number of observations, m, exceeds the
ber of independent variables, n. The sit
where m = n defines the general linear equ
problem. The situation where m < n produ
mathematical programming (optimization
lem.
6. The residuals are independent. Dependence
by similarity of adjacent values is known
tocorrelation.
7. If statistical tests of significance are to be
the conditional distribution of the depende
iable given the independent variables sho
normal.

When least squares regression is used as
dictive tool, only assumptions 4 and 5 need b
to produce acceptable estimates for the coeffi
If scientific explanation is the goal all the as
tions except 7 must hold. Assumption 7 is re
whenever tests of significance are carried out
tervals are estimated.

Equality of Regression Coefficients—Theory

The procedures used as the theoretical ba
this subroutine were presented in a college
in applied statistics by Dr. R. G. Krutchkoff a
ginia Polytechnic Institute and State Univ
Blacksburg. In the homogeneous case, the foll
equations are used:

$$SSE = \sum_i SSE_i$$

where:

SSE = combined error SS
SSE_i = ith equation error SS

$$DFE = \sum_i DF_i$$

where:

DFE = combined Deg. Freedom
DF_i = ith equation DF

$$MSE = SSE/DFE$$

$$MSE_i = SSE_i/DF_i$$

$$SSX_i = MSE_i/DF_i$$

$$D_i = 1/SSX_i$$

$$BB = \sum_i (B_i/D_i)/\sum_i (1/D_i) \qquad (24)$$

$$= \sum_i (B_i * SSX_i)/\sum_i SSX_i$$

ere

B_i = i'th regression coefficient

$$SSB = \sum_i (B_i - BB) ** 2/D_i) \qquad (25)$$

$$= \sum_i (B_i - BB) ** 2 * SSX_i$$

$$DF = K - 1 \qquad (26)$$

ere:

K = no. of coefficients compared

$$MSB = SSB/DF \qquad (27)$$

$$FB = MSB/MSE \qquad (28)$$

or the heterogeneous case, the computations are ollows:

SE see above (18)

$$DFE = (SSE)^2 / \sum_i (SSE_i^2 / DF_i) \qquad (29)$$

ound DFE down to the nearest integer

ISE see above (20)

$$BB = \sum_i (B_i/S2B_i) / \sum_i (1/S2B_i) \qquad (30)$$

re:

$S2B_i$ = ith coefficient variance; standard deviation squared

$$SSB = (\sum_i (B_i - BB) ** 2/S2B_i)) * MSE \qquad (31)$$

same as above (26)

B same as above (27)

same as above (28)

Program Code Documentation

'he programs are coded in the Microsoft (TM) 3IC language for direct use with the Radio Shack I) Level II BASIC interpreter. Unlike many other guages, BASIC allows concatenation of several cal statements in one physical line. Microsoft 3IC uses the colon, ":", as the logical statement meter. Because each physical line costs 5 bytes nemory and each unnecessary space 1 byte, small iputer BASIC programs are written in com-ssed code and appear impossible to decipher, es-ally for those who normally program in FOR-AN. To make matters worse, internal program imentation is reduced to a minimum in BASIC iuse these statements use precious memory. Given se memory constraints and the ability to refer mbiguously to any physical line in the program, I believe that adequate documentation of BASIC programs should be accomplished external to the code. Consequently, the code is presented in the Appendices in the normal, compressed fashion. Each section of code is explained in the following presentation by reference to physical linenumbers.

GLMR is composed of three separate programs: GLR/BAS, GLR1/BAS, and MULTPLT/BAS. The source code listings for these three programs are given in Appendices I, II, and III, respectively.

Program GLR/BAS

Linenumbers 13 to 695 comprise the same standard SEED program that was described in detail by Rauscher (1981). The general linear regression program, menu option number 8, begins with linenumber 2000. The matrix with the dependent variable, Y, and the matrix with the independent variable(s), X, must be resident on a data diskette prior to entering the regression program. Lines 2030 to 2043 request loading of the Y and X matrices. In addition, in line 2030, I transfer the matrix of dependent observations from the input/output matrix A(.,.) to the holding matrix Y(.,.), compute the total sum of squares, TSS, and the sum, MSS, of Y.

Line 2045 branches to the singular value decomposition subroutine located at line 1000. For a detailed presentation of the theory of least squares and the singular value decomposition see Forsythe *et al.* (1977). Lines 1000 to 1730 are a direct translation from the FORTRAN program SVD in chapter 9, pages 193 to 235 of Forsythe *et al.* (1977). The input to SVD is the A matrix which contains the independent variables. Upon return from SVD, W(.) contains the n unordered singular values of matrix A(.,.), and matrices U(.,.) and V(.,.) contain the orthogonal column vectors of U and V of the singular value decomposition (Forsythe *et al.* 1977). IE equals zero on a normal return from SVD, or else it is equal to K signifying that the K-th singular value has failed to converge after 30 iterations. This error is checked in line 2050 and fatally disrupts the program when IE does not equal to zero.

Lines 2060 to 2070 define WI as the value of the minimum singular value and WM the maximum, zero array B(.), and compute TA, which controls the effective rank in line 2080. The user is prompted to enter the number of significant digits in his or her raw data which is used to compute TA. This procedure is necessary to allow the computer to decide when a singular value is legitimately zero. In lines 2080 to 2100, I test for zero singular values (2080), set RR to the rank of the matrix, and calculate the regression coefficients in B(.).

In 2102 I check for singularity (RR < N where N is number of columns in matrix) warn the user of this fact if true, and save the minimum singular value in B(N+6) if the matrix is nonsingular or save -1 if singular. In location B(N+4) I save the scale factor, RE, for computing effective rank, B(N+5) is loaded with the maximum singular value, and B(N+7) is equated to the overall mean of the dependent variable (line 2104). The array B is simply a convenient place to store these miscellaneous data. Next, I compute the error sum of squares (line 2110), the sum of squares of the mean MSS, and the standard error of the mean SE (line 2120). Notice that variable MSS has been redefined and used again. In line 2120 I compute the predicted Y values YHAT, the error deviations EHAT, and the normalized error deviations ZHAT, and save them in column 2, 3, and 4 of matrix Y(.,.), respectively.

I then compute the sum of squares due to regression RSS, the regression sum of squares corrected for the mean RMSS, the corrected total sum of squares TMSS, and set the variable MEANS equal to TRUE if the first column of the independent matrix is a column of 1's (line 2030). A column of 1's signifies that an intercept coefficient is present in the regression model. Without a column of 1's, MEANS is set to FALSE and line 2160 is executed. Rank is increased by 1, the Ftostatistic is computed FR, and the subroutine FPROB (lines 10000 to 10500) is called to compute the critical value. The code variables for the ANOVA display are initialized and the program jumps to lines 2220 through 2345 to print the ANOVA table on the video display.

If MEANS is TRUE, the user is asked whether the term for the mean should be explicitly included in the ANOVA table or not. Lines 2190 and 2200 compute the necessary statistics and load the display variables with their values. Lines 2380 to 2410 saves the Y, $(X'X)^{-1}$, and B matrices to disk prior to loading the second program, GLRI. B(N+3) contains the rank, B(N+8) holds the number of coefficients N, and B(N+1) contains the error mean square.

Menu selection number 9 executes Bartlett's test for the homogeneity of variance. This subroutine implements the procedure presented by Sokal and Rohlf (1969, p. 370). The calculations are straightforward enough not to require additional documentation.

Program GLRI/BAS

Lines 13 to 695 are the same as the abov
tioned SEED program. Lines 700 to 920 man
menu display and operation. The variable FM
905) is a flag that, if FALSE, causes the intern
data matrices Y, X, B, and $(X'X)^{-1}$ to be load
disk into memory (lines 10000 to 10010). Onc
matrices have been loaded from disk, FMS
TRUE, thus bypassing the subroutine at line

Choosing Option number 8 leads to the con
interval calculations for the regression coef
(lines 1000 to 1090). The subroutine at lines
to 11090 calculates the T-table value for a tw
confidence interval. This subroutine also cal
and displays the standard error for each reg
coefficient. The standard error is required in
testing equality of regression lines (Option n

The confidence interval around the predic
values is computed in lines 2000 to 2130. Line
to 2130 allow the option to save the augmen
matrix to disk for use with the plotting routine
3000 to 3080 merge the X matrix with the Y
by columns and save the combined matrix to th
disk which must reside on disk number 1.
done to make the necessary column variables
able to the plotting program, which is automa
called in line 3080.

Lines 4000 to 4140 calculate and explain the
for multicollinearity. Lines 5000 to 5040 ma
location of a heteroscedasticity test that will
plemented at some future data. The code for t
tocorrelation check (lines 6000 to 6090) and the
B values (lines 7000 to 7130) is self explanat

Lines 8000 to 8230 contain the code to test
equality of regression coefficients. Lines 8022 t
guide the user and request the needed data in
the error variances are assumed homogeneous
8060 to 8090 are executed. If they are assume
erogeneous, lines 8200 to 8230 are execute
results are displayed in lines 8100 to 8140.

Program MULTPLT/BAS

Although the common input/output routine
in this program do not use the format of the
program that is used in GLR and GLR1, the fu
and structure of the routines are nearly the
Lines 2 to 18 contain a TRS-80 specific for
input routine functionally similar to that des

the SEED program by Rauscher (1981). Lines 19 20 and 21 to 24 contain the disk read and disk ite routines, respectively. Lines 26 to 31 contain ideo display routine. The dimension statements ed by this program are in lines 124, 130, and 131. es 34 to 43 solicit the required input information m the user. If data are not sorted, lines 46 to 64 form a matrix sort. Rows of the matrix are sorted ording to ascending values of the column desig ed as the X-axis. The graphing status control menu displayed in lines 66 to 74. Lines 75 to 102 contain the code for executing the plotting function on a lineprinter. This routine was adapted from Bahr (1979). Lines 103 to 118 perform the graphing status manipulations in the menu.

Lines 119 to 123 allow a function, defined in line 122, to generate the data to be plotted. The beginning, end, and interval values for the independent variable are used in a loop (121 to 123) to calculate the values of the dependent variable.

APPENDIX I. Source code listing for program GLR/BAS

```
10 CLEAR 300
    :TX=-1
    :GOTO700
    :'GLR/BAS  VERSION 10-21-80
13 '**************************************************
14 'ANSWER  INPUT ROUTINE
15 P=( 256*PEEK( 16417 )+PEEK( 16416 ))-15359
    :IF ABS( FL )=1THEN16ELSE24
16 IN$=""
    :PRINT@P,CHR$( 136 );
    :LX=1
17 IN$=INKEY$
    :IFIN$=""THEN22
18 IFFL=-1  AND  ASC( IN$ )>47  AND  ASC( IN$ )<58  THEN  21
19 IF FL=1  AND  ASC( IN$ )>64  AND  ASC( IN$ )<91  THEN  21
20 GOTO  22
21 PRINT@P,IN$
    :RETURN
22 LX=LX+1
    :IFL<16THEN17
23 PRINT@P,"  ";
    :FORLX=1TO25
    :NEXT
    :GOTO16
24 PRINT@P,  CHR$( 136 );
    :IN$=""
    :LX=ABS( FL )
    :GOSUB34
25 A$=INKEY$
    :IFA$=""THEN25
26 IFA$=CHR$( 13 )THENPRINTCHR$( 15 );
    :RETURN
27 IF  A$=CHR$( 8 )THENIFIN$<>""THENPRINTA$;
    :PRINTCHR$( 136 );CHR$( 24 );
    :IN$=LEFT$( IN$,LEN( IN$ )-1 )
    :LX=LX+1
    :GOTO25
    :ELSEGOTO28
28 IFA$=CHR$( 24 )THENPRINTCHR$( 29 );
    :GOTO24
29 IF  FL>0  AND  ASC( A$ )>31  AND  ASC( A$ )<91  THEN  32
30 IF  FL<0  AND  ASC( A$ )>=45  AND  ASC( A$ )<58  THEN  32
31 GOTO  25
32 IF  LX=0  THEN  25
```

```
33 PRINT A$;
    :IN$=IN$+A$
    :LX=LX-1
    :GOTO25
34 FOR IX=1TOLX-1
    :PRINT CHR$(136);
    :NEXT
    :FORJX=1TOLX
    :PRINT CHR$(24);
    :NEXT
    :RETURN
50 '*************************************
52 'CHANGE VARIABLE NAMES
54 '////////////////
56 CLS
    :PRINT@448,"WHICH COLUMN'S NAME WILL BE CHANGED? --> ";
    :FL=-2
    :GOSUB15
    :XJ=VAL(IN$)
    :PRINT
    :PRINT"PLEASE ENTER NEW NAME --> ";
    :FL=8
    :GOSUB15
    :N$(XJ)=IN$
    :RETURN
100 '********************************************
110 'READ SEQUENTIAL DATA SET FROM DISK
120 '///////////////////
125 CLS
130 PRINT@448,"ENTER FILENAME OF DESIRED DATA SET --> ";
    :INPUT F$
135 FF$=F$+"N"
    :L$=F$+"L"
    :F$=F$+"M"
140 OPEN "I",1,FF$
    :INPUT#1,R,C
    :CLOSE1
    :'GET R,C VALUES
145 OPEN "I",1,L$
    :FORK=1TOC
    :INPUT#1,N$(K)
    :NEXTK
146 CLOSE
150 OPEN "I",1,F$
    :
160 FORI=1TOR
    :FORJ=1TOC
    :INPUT#1,A(I,J)
    :NEXTJ,I
170 CLOSE 1
180 RETURN
190 '*************************************************
200 ' WRITE A SEQUENTIAL MATRIX TO DISK
210 '////////////////////
220 CLS
    :PRINT@448,"ENTER FILENAME OF NEW DATA SET --> ";
    :INPUT F$
    :PRINT
    :PRINT"ENTER DISK DRIVE # WHERE DATA SHOULD BE SAVED --> ";
    :INPUT DD$
222 FF$=F$+"N:"+DD$
    :L$=F$+"L:"+DD$
    :F$=F$+"M:"+DD$
225 FOR JQ=1TOC
    :IF LEN(N$(JQ))=0 THEN N$(JQ)=STR$(JQ)
226 NEXT
230 OPEN "O",1,FF$
    :PRINT#1,R;C;
    :CLOSE1
240 OPEN "O",1,F$
    :
250 FORI=1TOR
    :FORJ=1TOC
    :PRINT#1,A(I,J);
    :NEXTJ,I
260 CLOSE 1
265 OPEN"O",1,L$
    :FORI=1TOC
    :PRINT#1,N$(I);",";
    :NEXT
    :CLOSE
270 RETURN
290 REM **************************************************
295 REM               SUBROUTINE INPUT
300 '1.  THIS SUB READS FROM THE KEYBOARD
305 '2.  MATRIX A IS LOADED AND CAN BE SAVED ON DISK
325 '6.  14-APR-79
335 REM **************************************************
340 CLS
345 INPUT "PLEASE ENTER: NO. ROWS AND COLS (R,C).--> ";R,C
350 FL=8
    :PRINT
    :FOR J=1TOC
    :PRINT"ENTER THE NAME FOR VARIABLE ";J;" --> ";
    :GOSUB15
    :N$(J)=IN$
    :PRINT
    :NEXT
355 CLS
365 FOR I=1 TO R
370 PRINT "ROW ";I
375 FOR J=1 TO C
380 FL=-12
    :PRINT "PLEASE ENTER:  VALUE OF COLUMN ";J" --> ";
    :GOSUB 15
385 PRINT
390 A(I,J)=VAL(IN$)
395 NEXT J
400 NEXT I
430 RETURN
435 END
440 '***************************************************
445 '         SUBROUTINE VIDEO
450 '  DISPLAYS MATRIX A(R,C),13 ROWS BY 4 COLUMNS AT ONCE
455 ' USES ARROWS IN ALL DIRECTIONS TO SEE DIFFERENT PAGES
460 ' OF DATA.  "CLEAR" WILL TERMINATE DISPLAY
500 '*****************************************************
510 CLS
    :IFR=0 OR C=0 THEN RETURN ELSE JJ=INT(C/4.1+1)
    :II=INT(R/13.1+1)
515 I=1
    :J=1
525      IF R-13*I>=0.0 THEN N=13 ELSE N=13+(R-13*I)
535      IF C-4*J>=0.0 THEN L=4 ELSE L=4+(C-4*J)
```

```
540 CLS
    :PRINT"COL:";
    :FOR KK=0TO(L-1)
    :PRINT TAB(14*KK+8) N$((KK+1)+4*(J-1));
545 NEXT KK
    :PRINT
550 PRINT"-------------------------------------------------------------
555 FOR M=1 TO N
560 PRINT "R";M+13*(I-1);":";
565 FOR K=1 TO L
570 A=A(M+13*(I-1),K+4*(J-1))
575 PRINT TAB(14*(K-1)+8) A;
580 NEXT K
    :PRINT
585 NEXT M
586 A$=INKEY$
    :IFA$=""GOTO586
587 IF ASC(A$)=31THEN619ELSEIFASC(A$)=9THEN588ELSE590
588 IFJ+1>JJTHENJ=1ELSEJ=J+1
589 GOTO 525
590 IF ASC(A$)=8THEN591ELSE593
591 IF J-1<=0THENJ=JJ ELSE J=J-1
592 GOTO 525
593 IF ASC(A$)=10THEN594ELSE596
594 IF I+1>IITHENI=1ELSEI=I+1
595 GOTO 525
596 IF ASC(A$)=91THEN597ELSE599
597 IF I-1<=0THENI=IIELSEI=I-1
598 GOTO 525
599 IF ASC(A$)=64 THEN 600 ELSE 601
600 GOSUB 670
    :GOTO525
601 IF ASC(A$)=46 THEN GOSUB 50 ELSE 618
602 GOTO 525
618 GOTO586
619 RETURN
    :END
620 '**************************************************
622 'LINEPRINTER OUTPUT ROUTINE
623 IF R=0 OR C=0 THEN RETURN
624 AN$="DATA SET NAME --> "
    :CLS
    :PRINT@448,"PRESS <ENTER> WHEN PRINTER IS READY.";
    :INPUT AN
    :T$=LEFT$(F$,LEN(F$)-1)
    :T$=AN$+T$
    :GOSUB42000
    :LPRINT TAB(ZZ);T$
    :LPRINT " "
    :LPRINT " "
630 JJ=INT(C/4.1+1)
    :II=INT(R/200.1+1)
632 FORI=1TOII
634 IFR-200*I>=0.0THENN=200ELSEN=200+(R-200*I)
636 FORJ=1TOJJ
638 IFC-4*J>=0.0THENL=4ELSE L=4+(C-4*J)
640 LPRINT"COL:";
    :FORKK=0TO(L-1)
    :LPRINT TAB(14*KK+8) N$((KK+1)+4*(J-1));
642 NEXT KK
644 LPRINT" "
646 LPRINT"------------------------------------------------------------
```

```
648 FOR M=1TON
650 LPRINT "R";M+200*(I-1);":";
652 FOR K=1TO L
654 A=A(M+200*(I-1),K+4*(J-1))
656 LPRINT TAB(14*(K-1)+8) A;
658 NEXT K
660 LPRINT
662 NEXT M
664 LPRINT " "
    :LPRINT " "
    :LPRINT " "
666 NEXT J,I
668 RETURN
670 '**********************************
671 'SCREEN PRINT ROUTINE-  ACTIVATED BY PROGRAMMED "@" ASC(64)
672 '//////////////////////
673 IF PEEK(14312)<>63 THEN RETURN
674 LPRINT STRING$(64,"+")
675 FOR N= 15360 TO 16383 STEP 64
676 A$=" "
679 FOR Q=0TO63
680 Z=PEEK(N+Q)
    :IFZ>0ANDZ<27THENZ=Z+64ELSEIFZ<32THENZ=32
681 IFZ>=127 AND Z<=191 THEN Z=42
682 B$=CHR$(Z)
683 A$=A$+B$
684 NEXT Q
685 IF PEEK(14312)<>63THEN RETURN
686 LPRINT " "
    :LPRINT A$
687 NEXT N
688 LPRINT STRING$(64,"+")
689 FORN=1TO3
    :LPRINT "  "
    :NEXT
690 RETURN
695 RUN"MAIN/BAS"
    :END
700 '**************************************************
710 'GENERALIZED I/O SUBROUTINES FOR PROGRAM STARTERS
720 '////////////////////
735 CLS
    :T$="NORTHERN HARDWOODS LABORATORY, USFS, MARQUETTE, MI"
    :GOSUB42000
736 T$="////////////////////////////////////////////////////////////"
    :GOSUB42000
737 PRINT
738 T$="MENU FOR:  GENERAL LINEAR REGRESSION ANALYSIS SYSTEM
739 GOSUB42000
    :PRINT
740 IF TX=-1 THEN GOSUB 40000 ELSE 750
750 TX=1
    :PRINT"  1.  RETURN TO MAIN MENU          2.  GOTO BASIC
760 PRINT"  3.  READ A MATRIX FROM DISK       4.  WRITE A MATRIX TO DISK
770 PRINT"  5.  ENTER A MATRIX MANUALLY       6.  DISPLAY MATRIX ON VIDEO
780 PRINT"  7.  PRINT MATRIX                  8.  GENERAL LINEAR REGRESSION
790 PRINT"  9.  BARTLETT'S TEST FOR HOMOGENEITY OF VARIANCES"
900 PRINT
    :PRINT"SELECT ONE OF THE ABOVE --> ";
    :FL=-2
    :GOSUB15
    :AN=VAL(IN$)
    :IFAN<=0ORAN>16THEN740
910 ON AN GOSUB 695,43000,125,220,340,510,620,2000,3000
920 GOTO 735
1000 '*********************************************
1010 'SINGULAR VALUE DECOMPOSITION
1020 'FORSYTHE 1977 CH.9 PP.193-235
1030 'INPUT
    : A(M,N) WHERE M>=N
1040 'OUTPUT
    : W CONTAINS N UNORDERED SINGULAR VALUES OF A
1050 '          U & V CONTAIN THEMSELVES
1060 '/////////////////////////
1065 MV$="TRUE"
    :MU$="TRUE"
1070 IE=0
    :R1=R
    :C1=C
    :M=R
    :N=C
    :NM=R
    :FORI=1TOM
    :FORJ=1TON
    :U(I,J)=A(I,J)
    :NEXTJ,I
1080 'HOUSEHOLDER REDUCTION TO BIDIAGONAL FORM
1090 G=0
    :SCALE=0
    :AR=0
1100 FORI=1TON
    :L=I+1
    :RV1(I)=SCALE*G
    :G=0
    :S=0
    :SCALE=0
    :IFI>MTHEN1160
1110 FORK=ITOM
    :SCALE=SCALE+ABS(U(K,I))
    :NEXTK
    :IFSCALE=0THEN1160
1120 FORK=ITOM
    :U(K,I)=U(K,I)/SCALE
    :S=S+U(K,I)[2
    :NEXTK
1130 F=U(I,I)
    :SS=SGN(F)
    :G=-1*SS*ABS(SQR(S))
    :H=F*G-S
    :U(I,I)=F-G
    :IFI=NTHEN1150
1140 FORJ=LTON
    :S=0
    :FORK=ITOM
    :S=S+U(K,I)*U(K,J)
    :NEXTK
    :F=S/H
    :FORK=ITOM
    :U(K,J)=U(K,J)+F*U(K,I)
    :NEXTK
    :NEXTJ
1150 FORK=ITOM
    :U(K,I)=SCALE*U(K,I)
    :NEXTK
```

```
1160 W( I )=SCALE*G
     :G=0
     :S=0
     :SCALE=0
     :IFI>MORI=NTHEN1230
1170 FORK=LTON
     :SCALE=SCALE+ABS( U( I,K ))
     :NEXTK
     :IFSCALE=0THEN1230
1180 FORK=LTON
     :U( I,K )=U( I,K )/SCALE
     :S=S+U( I,K )[2
     :NEXTK
1190 F=U( I,L )
     :SS=SGN( F )
     :G=-1*SS*ABS( SQR( S ))
     :H=F*G-S
     :U( I,L )=F-G
1200 FORK=LTON
     :RV1( K )=U( I,K )/H
     :NEXTK
     :IFI=MTHEN1220
1210 FORJ=LTOM
     :S=0
     :FORK=LTON
     :S=S+U( J,K )*U( I,K )
     :NEXTK
     :FORK=LTON
     :U( J,K )=U( J,K )+S*RV1( K )
     :NEXTK
     :NEXTJ
1220 FORK=LTON
     :U( I,K )=SCALE*U( I,K )
     :NEXTK
1230 TT=ABS( W( I ))+ABS( RV1( I ))
     :IFTT>ARTHENAR=TT
1240 NEXTI
1250 'FORM THE V MATRIX IF MV="TRUE"
1260 IFMV$="TRUE"THEN1270ELSE1350
1270 FORII=1TON
     :I=N+1-II
     :IFI=NTHEN1320
1280 IFG=0THEN1310
1290 FORJ=LTON
     :V( J,I )=( U( I,J )/U( I,L ))/G
     :NEXTJ
1300 FORJ=LTON
     :S=0
     :FORK=LTON
     :S=S+U( I,K )*V( K,J )
     :NEXTK
     :FORK=LTON
     :V( K,J )=V( K,J )+S*V( K,I )
     :NEXTK
     :NEXTJ
1310 FORJ=LTON
     :V( I,J )=0
     :V( J,I )=0
     :NEXTJ
1320 V( I,I )=1.0
     :G=RV1( I )
     :L=I
```

```
1330 NEXT II
1340 'COMPUTE U IF MU="TRUE"
1350 IFMU$="TRUE"THEN1360ELSE1470
1360 MN=N
     :IFM<NTHENMN=M
1370 FORII=1TOMN
     :I=MN+1-II
     :L=I+1
     :G=W(I)
     :IFI=0THEN1390
1380 FORJ=LTON
     :U(I,J)=0
     :NEXTJ
1390 IFG=0THEN1430
1400 IFI=MNTHEN1420
1410 FORJ=LTON
     :S=0
     :FORK=LTOM
     :S=S+U(K,I)*U(K,J)
     :NEXTK
     :F=(S/U(I,I))/G
     :FORK=ITOM
     :U(K,J)=U(K,J)+F*U(K,I)
     :NEXTK
     :NEXTJ
1420 FORJ=ITOM
     :U(J,I)=U(J,I)/G
     :NEXTJ
     :GOTO1440
1430 FORJ=ITOM
     :U(J,I)=0
     :NEXTJ
1440 U(I,I)=U(I,I)+1
1450 NEXTII
1460 'DIAGONALIZATION OF THE BIDIAGONAL FORM
1470 FORKK=1TON
     :K1=N-KK
     :K=K1+1
     :ITS=0
1480 FORLL=1TOK
     :L1=K-LL
     :L=L1+1
     :IF(ABS(RV1(L))+AR)=ARTHEN1560
1490 IF(ABS(W(L1))+AR)=ARTHEN1510
1500 NEXTLL
1510 C=0
     :S=1
     :FORI=LTOK
     :F=S*RV1(I)
     :IF(ABS(F)+AR)=ARTHEN1560
1520 G=W(I)
     :H=SQR(F*F+G*G)
     :W(I)=H
     :C=G/H
     :S=-F/H
     :IFMU$="TRUE"THEN1530ELSE1540
1530 FORJ=1TOM
     :Y=U(J,L1)
     :Z=U(J,I)
     :U(J,L1)=Y*C+Z*S
     :U(J,I)=-Y*S+Z*C
     :NEXTJ
```

```
1540 NEXTI
1550 'TEST FOR CONVERGENCE
1560 Z=W(K)
    :IFL=KTHEN1670
1570 IFITS=30THEN1720
1580 ITS=ITS+1
    :X=W(L)
    :Y=W(K1)
    :G=RV1(K1)
    :H=RV1(K)
    :F=((Y-Z)*(Y+Z)+(G-H)*(G+H))/(2*H*Y)
    :G=SQR(F*F+1)
    :SS=SGN(F)
    :SF=SS*ABS(G)
    :F=((X-Z)*(X+Z)+H*(Y/(F+SF)-H))/X
    :C=1
    :S=1
1590 FORII=LTOK1
    :I=II+1
    :G=RV1(I)
    :Y=W(I)
    :H=S*G
    :G=C*G
    :Z=SQR(F*F+H*H)
    :RV1(II)=Z
    :C=F/Z
    :S=H/Z
    :F=X*C+G*S
    :G=-X*S+G*C
    :H=Y*S
    :Y=Y*C
    :IFMV$="TRUE"THEN1600ELSE1610
1600 FORJ=1TON
    :X=V(J,II)
    :Z=V(J,I)
    :V(J,II)=X*C+Z*S
    :V(J,I)=-X*S+Z*C
    :NEXTJ
1610 Z=SQR(F*F+H*H)
    :W(II)=Z
    :IFZ=0THEN1630
1620 C=F/Z
    :S=H/Z
1630 F=C*G+S*Y
    :X=-S*G+C*Y
    :IFMU$="TRUE"THEN1640ELSE1650
1640 FORJ=1TOM
    :Y=U(J,II)
    :Z=U(J,I)
    :U(J,II)=Y*C+Z*S
    :U(J,I)=-Y*S+Z*C
    :NEXTJ
1650 NEXTII
1660 RV1(L)=0
    :RV1(K)=F
    :W(K)=X
    :GOTO1480
1670 IFZ>=0THEN1700
1680 W(K)=-Z
    :IFMV$="TRUE"THEN1690ELSE1700
1690 FORJ=1TON
    :V(J,K)=-V(J,K)
    :NEXTJ
1700 NEXTKK
1710 GOTO1730
1720 IE=K
1730 RETURN
2000 '***************************************
2010 'LINEAR REGRESSION CONTROL MODULE
2020 '///////////////////////
2030 CLS
    :PRINT@128,"ENTER VECTOR Y( M ) IN X*B=Y  WHERE R=M & C=1."
    :GOSUB130
    :TSS=0
    :MSS=0
    :FORI=1TOR
    :Y( I,1 )=A( I,1 )
    :TSS=TSS+Y( I,1 )*Y( I,1 )
    :MSS=MSS+Y( I,1 )
    :NEXTI
2040 CLS
    :PRINT@128,"ENTER MATRIX X( M,N ) OF X*B=Y."
    :GOSUB130
2042 IFF$="XM"THEN2045ELSEF$="X"
2043 DD$="1"
    :GOSUB222
2045 CLS
    :PRINT@458,"PLEASE BE PATIENT.  COMPUTATIONS IN PROGRESS."
    :GOSUB 1000
    :'SVD
2050 IF IE<>0THENCLS
    :PRINT@458,"ERROR RETURN FROM SVD"
    :STOP
2060 WI=10000
    :WM=0
    :FORJ=1TON
    :IFW( J )>WMTHENWM=W( J )
2065 IFW( J )<WITHENWI=W( J )
2070 B( J )=0
    :NEXTJ
    :CLS
    :PRINT@448,"NUMBER OF SIGNIFICANT FIGURES IN RAW DATA? --> ";
    :FL=-1
    :GOSUB15
    :S=VAL( IN$ )
    :S=S+2
    :RE=0.1[S
    :TA=RE*WM
    :'TA SETS EFFECTIVE RANK AND IS ARBITRARILY COMPUTED
2080 RR=0
    :FORJ=1TON
    :IFW( J )<=TATHEN2100
2090 RR=RR+1
    :S=0
    :FORI=1TOM
    :S=S+U( I,J )*Y( I,1 )
    :NEXTI
    :S=S/W( J )
    :FORI=1TON
    :B( I )=B( I )+S*V( I,J )
    :NEXTI
    :SV( J )=( 1/W( J ) )[2
```

```
00 NEXTJ
02 IFRR<NTHENB(N+6)=-1
  :PRINT
  :PRINT"WARNING!!  MATRIX IS SINGULAR."
  :ELSEB(N+6)=WI
04 B(N+4)=RE
  :B(N+5)=WM
  :B(N+7)=MSS/M
10 ESS=0
  :FORI=1TOM
  :RI=0
  :FORJ=1TON
  :RI=RI+B(J)*A(I,J)
  :NEXTJ
  :ESS=ESS+(RI-Y(I,1))[2
  :NEXTI
20 MSS=M*(MSS/M)[2
  :SE=SQR(ESS/(M-RR))
  :FORI=1TOM
  :Y(I,2)=0
  :FORJ=1TON
  :Y(I,2)=Y(I,2)+A(I,J)*B(J)
  :NEXTJ
  :Y(I,3)=Y(I,1)-Y(I,2)
  :Y(I,4)=Y(I,3)/SE
  :NEXTI
30 RSS=TSS-ESS
  :RMSS=RSS-MSS
  :TMSS=TSS-MSS
  :IFA(1,1)=1ANDA(INT(N/2),1)=1ANDA(N,1)=1THENMEAN$="TRUE"ELSEMEAN$="FALSE"
40 'DECISION BRANCHES FOR ANOVA TABLES
50 IFMEAN$="TRUE"THEN2170
60 RR=RR+1
  :FR=(RSS/RR)/(ESS/(M-RR))
  :DN=RR
  :DD=M-RR
  :GOSUB10000
  :A6=RR
  :A7=RSS
  :A8=RSS/RR
  :A9=FR
  :Z1=FB
  :Z2=M
  :Z3=TSS
  :GOTO2220
70 CLS
  :PRINT@448,"INCLUDE TERM FOR MEAN IN ANOVA? (Y/N) --> ";
  :FL=1
  :GOSUB15
  :IFIN$="Y"THENFM$="TRUE"ELSEFM$="FALSE"
80 IFFM$="FALSE"THEN2200
90 A1=1
  :A2=MSS
  :A3=MSS
  :FR=MSS/(ESS/(M-RR))
  :A4=FR
  :DN=1
  :DD=M-RR
  :GOSUB10000
  :A5=FB
```

```
    :A6=RR-1
    :A7=RMSS
    :A8=RMSS/(RR-1)
    :FR=A8/(ESS/(M-RR))
    :A9=FR
    :DN=RR-1
    :DD=M-RR
    :GOSUB10000
    :Z1=FB
    :Z2=M
    :Z3=TSS
    :GOTO2220
2200 A6=RR-1
    :A7=RMSS
    :A8=RMSS/(RR-1)
    :A9=A8/(ESS/(M-RR))
    :FR=A9
    :DN=RR-1
    :DD=M-RR
    :GOSUB10000
    :Z1=FB
    :Z2=M-1
    :Z3=TMSS
2210 'ANOVA TABLE DISPLAY
2220 CLS
    :PRINT@10,"REGRESSION ANALYSIS OF VARIANCE TABLE"
2230 PRINT@128,"SOURCE";TAB(7)"DF";TAB(15)"SS";TAB(28)"MS";TAB(43)"F";TAB(50)"PR
BABILITY"
2240 PRINT@192,"----------------------------------------------------------------"
2250 IFFM$="TRUE"THEN2260ELSE2270
2260 PRINT"MEAN";TAB(6)A1;TAB(12)A2;TAB(25)A3;TAB(40)A4;TAB(53);USING"#.####";A5
2270 PRINT"REG.";TAB(6)A6;TAB(12)A7;TAB(25)A8;TAB(40)A9;TAB(53);USING"#.####";Z1
2280 PRINT"ERROR";TAB(6)M-RR;TAB(12)ESS;TAB(25)ESS/(M-RR)
2290 PRINT"---------------------------------------------------------------"
2300 PRINT"TOTAL";TAB(6)Z2;TAB(12)Z3
2305 PRINT"MEAN OF RESPONSE VARIABLE Y = "B(N+7)
2310 PRINT"STD.DEV. OF ERROR= "SQR(ESS/(M-RR));"  C.V. OF Y = ";USING"###.#";((S
R(ESS/(M-RR)))/B(N+7))*100
    :IFMEAN$="TRUE"THENR2=RMSS/TMSSELSER2=RSS/TSS
2312 PRINT"MULTIPLE CORRELATION COEFFICIENT (R**2) = ";R2
    :PRINT"REGRESSION COEFFICIENTS"
    :FORI=0TON-1
    :IFMEAN$="FALSE"THEN2330
2320 PRINT"B"I"= "B(I+1),
    :GOTO2340
2330 PRINT"B"I+1"= "B(I+1),
2340 NEXTI
2345 A$=INKEY$
    :IFA$=""THEN2345ELSEIFASC(A$)=64THENGOSUB670
2350 IFMEAN$="FALSE"THEN2380
2360 IFFM$="TRUE"THENB$="WITHOUT"ELSEB$="WITH"
2370 CLS
    :PRINT@448,"WANT TO VIEW THE ANOVA "B$" THE MEAN? (Y/N) --> ";
    :FL=1
    :GOSUB15
    :IFIN$="N"THEN2380ELSEIFIN$="Y"ANDB$="WITH"THENFM$="TRUE"
    :GOTO2190
    :ELSEFM$="FALSE"
    :GOTO2200
2380 'SAVE Y,(X'X)-1,AND B WITH B(0)=RR
```

```
2 CLS
 :PRINT@448,"COMPUTE CONFIDENCE INTERVALS OR DO ERROR ANALSIS? (Y/N) --> ";
 :FL=1
 :GOSUB15
 :IFIN$="N"THENRETURN
5 CLS
 :PRINT@448,"MATRICES Y(.,4), (X'X)-1, AND B(.) WILL NOW BE SAVED."
 :PRINT"BE SURE A DATA DISK IS IN DRIVE #1."
 :PRINT
 :PRINT"<ENTER> TO CONTINUE."
6 A$=INKEY$
 :IFA$=""THEN2386
0 FORI=1TOM
 :FORJ=1TO4
 :A( I,J )=Y( I,J )
 :NEXTJ,I
 :FF$="YN:1"
 :L$="YL:1"
 :F$="YM:1"
 :N$( 1 )="Y"
 :N$( 2 )="YHAT"
 :N$( 3 )="EHAT"
 :N$( 4 )="ZHAT"
 :R=M
 :C=4
 :GOSUB225
5 IFMEAN$="TRUE"THENB( N+2 )=1ELSEB( N+2 )=2
0 B( N+8 )=N
 :B( N+1 )=ESS/( M-RR )
 :B( N+3 )=RR
 :FORI=1TON+8
 :A( I,1 )=B( I )
 :NEXTI
 :N$( 1 )="1"
 :FF$="BN:1"
 :L$="BL:1"
 :F$="BM:1"
 :R=N+8
 :C=1
 :GOSUB225
5 FORI=1TON
 :N$( I )=STR$( I )
 :NEXTI
 :'SET COLUMN LABELS CORRECTLY
10 FORI=1TON
 :FORJ=1TON
 :U( I,J )=SV( I )*V( J,I )
 :NEXTJ,I
 :FORI=1TON
 :FORJ=1TON
 :A( I,J )=0
 :FORK=1TON
 :A( I,J )=A( I,J )+V( I,K )*U( K,J )
 :NEXTK,J,I
 :FF$="XPXIN:1"
 :L$="XPXIL:1"
 :F$="XPXIM:1"
 :R=N
 :C=N
 :GOSUB225
```

```
2420 RUN"GLR1/BAS"
3000 '****************************************
3010 'BARTLETT'S TEST FOR HOMOGENEITY OF VARIANCES
3020 '     AFTER
    : SOKAL AND ROLFE 1969, PP. 370-371
3030 'USER MUST INPUT VARIANCES AND THEIR DF'S
3040 '////////////////////////////////////////
3050 CLS
    :PRINT@448,"TO USE THIS ROUTINE YOU MUST HAVE THE VARIANCES AND THEIR DEGREE
  OF FREEDOM.  THEY ARE NOT COMPUTED FOR YOU IN THIS ROUTINE."
    :PRINT
    :PRINT"ENTER <Y> IF YOU HAVE THEM AND <N> IF YOU DO NOT."
    :PRINT
    :PRINT"ENTER --> ";
3060 FL=1
    :GOSUB15
    :IFIN$="Y"THEN3070ELSERETURN
3070 CLS
    :PRINT@448,"ENTER THE NUMBER OF VARIANCES TO BE COMPARED --> ";
    :FL=-2
    :GOSUB15
    :N1=VAL(IN$)
    :R=N1
    :C=2
    :N$(1)="VARIANCE"
    :N$(2)="D.F"
3075 CLS
    :PRINT"ENTER VARIANCE S2(I) AND D.F.= N(I)-1."
    :PRINT
3080 FORI=1TON1
    :PRINT"VARIANCE #"I"=";
    :FL=-3
    :GOSUB15
    :A(I,1)=VAL(IN$)
    :PRINT"          DF #"I"=";
    :FL=-3
    :GOSUB15
    :A(I,2)=VAL(IN$)
    :PRINT
    :NEXTI
3090 CLS
    :PRINT@448,"DO YOU WISH TO REVIEW THE ENTRIES ABOVE? (Y/N) --> ";
    :FL=1
    :GOSUB15
    :IFIN$="N"THEN3100ELSEGOSUB510
3100 CLS
    :PRINT@448,"ENTER <C> TO CONTINUE, <R> TO RESTART DATA ENTRY. --> ";
    :FL=1
    :GOSUB15
    :IFIN$="C"THEN3110ELSE3030
3110 CLS
    :PRINT@448,"TO AVOID NEGATIVE LOGARITHMS, ALL VARIANCES MUST BE GREATER"
    :PRINT"THAN ONE (1.0).  ARE THEY? (Y/N) --> ";
    :FL=1
    :GOSUB15
    :IFIN$="Y"THEN3130
3120 PRINT
    :PRINT"ENTER THE CONSTANT MULTIPLIER TO INSURE NO NEG. LOGS --> ";
    :FL=4
    :GOSUB15
```

```
   :C1=VAL(IN$)
   :FORI=1TON1
   :A(I,1)=C1*A(I,1)
   :NEXTI
   :GOSUB510
3130 CLS
   :PRINT@458,"PLEASE BE PATIENT.  COMPUTATIONS IN PROGRESS."
3140 S5=0
   :S4=0
   :S1=0
   :S2=0
   :FORI=1TON1
   :S1=S1+A(I,2)
   :S2=S2+A(I,2)*A(I,1)
   :S4=S4+A(I,2)*(LOG(A(I,1))/LOG(10))
   :S5=S5+1/A(I,2)
   :NEXTI
   :S3=S2/S1
   :S3=LOG(S3)/LOG(10)
3150 CHI2=2.3026*((S1*S3)-S4)
3170 CF=1+(1/(3*(N1-1)))*(S5-(1/S1))
   :CHI2=CHI2/CF
3180 CLS
   :PRINT@448,"CHI SQUARED = "CHI2" WITH "N1-1" DF."
   :PRINT
   :PRINT"REJECT HOMOGENEITY OF VARIANCES IF CALCULATED VALUE (ABOVE) IS  GREATE
R THAN TABLE VALUE. (LOOK IT UP)"
   :PRINT
   :PRINT"<ENTER> TO RETURN TO MAIN MENUE."
3190 A$=INKEY$
   :IFA$=""THEN3190ELSERETURN
10000 '*************************************
10010 'SUBROUTINE  FPROB
10040 'INPUT
   : FR=R RATIO  DN=NUMERATOR DF  DD=DENOMINATOR DF
10050 'OUTPUT
   : FB= PROBABILITY OF F
10060 '//////////////////////
10065 X#=1
   :IFFR<1THEN10080
10070 S#=DN
   :T#=DD
   :ZZ#=FR
   :GOTO10090
10080 S#=DD
   :T#=DN
   :ZZ#=1/FR
10090 J5=2/9/S#
   :K5=2/9/T#
   :Z#=K5*ZZ#[(2/3)+J5
   :GOSUB10500
   :Y#=ABS((1-K5)*ZZ#[(1/3)-1+J5)/Z3#
   :IFT#<4THEN10110
10100 X#=.5/(1+Y#*(.196854+Y#*(.115194+Y#*(.000344+Y#*.019527))))[4
   :X#=INT(X#*10000+.5)/10000
   :GOTO10120
10110 Y#=Y#*(1+.03*Y#[4/T#[3)
   :GOTO10100
10120 IFF#>1THEN10140
10130 X#=1-X#
```

```
10140 FB=1-X#
10150 RETURN
10500 Z3#=SQR( Z# )
    :Z3#=( Z3#+Z#/Z3# )/2
    :Z3#=( Z3#+Z#/Z3# )/2
    :RETURN
40000 M=100
    :N=10
    :DIM N$( N ),A( M,N ),W( N ),U( M,N ),V( N,N ),RV1( N ),Y( M,4 ),B( N+8 ),SV( N ),XI( N,N )
40015 MV=-99.99
40020 RETURN
42000 CC=LEN( T$ )
    :ZZ=INT( 30-CC/2 )
    :PRINT TAB( ZZ );T$
    :RETURN
    :'CENTERING ROUTINE
43000 END
```

APPENDIX II. Source code listing for program GLR1/BAS

```
10 CLEAR 500
   :TX=-1
   :GOTO700
   :'GLR1/BAS  VERSION 02/19/81
13 '*************************************************
14 'ANSWER INPUT ROUTINE
15 P=(256*PEEK(16417)+PEEK(16416))-15359
   :IF ABS(FL)=1THEN16ELSE24
16 IN$=""
   :PRINT@P,CHR$(136);
   :LX=1
17 IN$=INKEY$
   :IFIN$=""THEN22
18 IFFL=-1 AND ASC(IN$)>47 AND ASC(IN$)<58 THEN 21
19 IF FL=1 AND ASC(IN$)>64 AND ASC(IN$)<91 THEN 21
20 GOTO 22
21 PRINT@P,IN$
   :RETURN
22 LX=LX+1
   :IFL<16THEN17
23 PRINT@P," ";
   :FORLX=1TO25
   :NEXT
   :GOTO16
24 PRINT@P, CHR$(136);
   :IN$=""
   :LX=ABS(FL)
   :GOSUB34
25 A$=INKEY$
   :IFA$=""THEN25
26 IFA$=CHR$(13)THENPRINTCHR$(15);
   :RETURN
27 IF A$=CHR$(8)THENIFIN$<>""THENPRINTA$;
   :PRINTCHR$(136);CHR$(24);
   :IN$=LEFT$(IN$,LEN(IN$)-1)
   :LX=LX+1
   :GOTO25
   :ELSEGOTO28
28 IFA$=CHR$(24)THENPRINTCHR$(29);
   :GOTO24
29 IF FL>0 AND ASC(A$)>31 AND ASC(A$)<91 THEN 32
30 IF FL<0 AND ASC(A$)>=45 AND ASC(A$)<58 THEN 32
31 GOTO 25
32 IF LX=0 THEN 25
33 PRINT A$;
   :IN$=IN$+A$
   :LX=LX-1
   :GOTO25
34 FOR IX=1TOLX-1
   :PRINT CHR$(136);
   :NEXT
   :FORJX=1TOLX
   :PRINT CHR$(24);
   :NEXT
   :RETURN
50 '************************************
52 'CHANGE VARIABLE NAMES
54 '/////////////
56 CLS
   :PRINT@448,"WHICH COLUMN'S NAME WILL BE CHANGED? --> ";
```

```
    :FL=-2
    :GOSUB15
    :XJ=VAL(IN$)
    :PRINT
    :PRINT"PLEASE ENTER NEW NAME --> ";
    :FL=8
    :GOSUB15
    :N$(XJ)=IN$
    :RETURN
100 '*******************************************
110 'READ SEQUENTIAL DATA SET FROM DISK
120 '///////////////
125 CLS
130 PRINT@448,"ENTER FILENAME OF DESIRED DATA SET --> ";
    :INPUT F$
135 FF$=F$+"N"
    :L$=F$+"L"
    :F$=F$+"M"
140 OPEN "I",1,FF$
    :INPUT#1,R,C
    :CLOSE1
    :'GET R,C VALUES
145 OPEN "I",1,L$
    :FORK=1TOC
    :INPUT#1,N$(K)
    :NEXTK
146 CLOSE
150 OPEN "I",1,F$
    :
160 FORI=1TOR
    :FORJ=1TOC
    :INPUT#1,A(I,J)
    :NEXTJ,I
170 CLOSE 1
180 RETURN
190 '***********************************************
200 ' WRITE A SEQUENTIAL MATRIX TO DISK
210 '/////////////////
220 CLS
    :PRINT@448,"ENTER FILENAME OF NEW DATA SET --> ";
    :INPUT F$
    :PRINT
    :PRINT"ENTER DISK DRIVE # WHERE DATA SHOULD BE SAVED --> ";
    :INPUT DD$
222 FF$=F$+"N:"+DD$
    :L$=F$+"L:"+DD$
    :F$=F$+"M:"+DD$
225 FOR JQ=1TOC
    :IF LEN(N$(JQ))=0 THEN N$(JQ)=STR$(JQ)
226 NEXT
230 OPEN "O",1,FF$
    :PRINT#1,R;C;
    :CLOSE1
240 OPEN "O",1,F$
    :
250 FORI=1TOR
    :FORJ=1TOC
    :PRINT#1,A(I,J);
    :NEXTJ,I
260 CLOSE 1
```

```
265 OPEN"O",1,L$
    :FORI=1TOC
    :PRINT#1,N$(I);",";
    :NEXT
    :CLOSE
270 RETURN
290 REM ****************************************************
295 REM                 SUBROUTINE INPUT
300 '1.  THIS SUB READS FROM THE KEYBOARD
305 '2.  MATRIX A IS LOADED AND CAN BE SAVED ON DISK
325 '6.  14-APR-79
335 REM ****************************************************
340 CLS
345 INPUT "PLEASE ENTER: NO. ROWS AND COLS (R,C).--> ";R,C
350 FL=8
    :PRINT
    :FOR J=1TOC
    :PRINT"ENTER THE NAME FOR VARIABLE ";J;" --> ";
    :GOSUB15
    :N$(J)=IN$
    :PRINT
    :NEXT
355 CLS
365 FOR I=1 TO R
370 PRINT "ROW ";I
375 FOR J=1 TO C
380 FL=-12
    :PRINT "PLEASE ENTER:  VALUE OF COLUMN ";J" --> ";
    :GOSUB 15
385 PRINT
390 A(I,J)=VAL(IN$)
395 NEXT J
400 NEXT I
430 RETURN
435 END
440 '****************************************************
445 '           SUBROUTINE VIDEO
450 '  DISPLAYS MATRIX A(R,C),13 ROWS BY 4 COLUMNS AT ONCE
455 ' USES ARROWS IN ALL DIRECTIONS TO SEE DIFFERENT PAGES
460 ' OF DATA.  "CLEAR" WILL TERMINATE DISPLAY
500 '******************************************************
510 CLS
    :IFR=0 OR C=0 THEN RETURN ELSE JJ=INT(C/4.1+1)
    :II=INT(R/13.1+1)
515 I=1
    :J=1
525      IF R-13*I>=0.0 THEN N=13 ELSE N=13+(R-13*I)
535      IF C-4*J>=0.0 THEN L=4 ELSE L=4+(C-4*J)
540 CLS
    :PRINT"COL:";
    :FOR KK=0TO(L-1)
    :PRINT TAB(14*KK+8) N$((KK+1)+4*(J-1));
545 NEXT KK
    :PRINT
550 PRINT"----------------------------------------------------------------"
555 FOR M=1 TO N
560 PRINT "R";M+13*(I-1);":";
565 FOR K=1 TO L
570 A=A(M+13*(I-1),K+4*(J-1))
575 PRINT TAB(14*(K-1)+8) A;
```

```
580 NEXT K
    :PRINT
585 NEXT M
586 A$=INKEY$
    :IFA$=""GOTO586
587 IF ASC(A$)=31THEN619ELSEIFASC(A$)=9THEN588ELSE590
588 IFJ+1>JJTHENJ=1ELSEJ=J+1
589 GOTO 525
590 IF ASC(A$)=8THEN591ELSE593
591 IF J-1<=0THENJ=JJ ELSE J=J-1
592 GOTO 525
593 IF ASC(A$)=10THEN594ELSE596
594 IF I+1>IITHENI=1ELSEI=I+1
595 GOTO 525
596 IF ASC(A$)=91THEN597ELSE599
597 IF I-1<=0THENI=IIELSEI=I-1
598 GOTO 525
599 IF ASC(A$)=64 THEN 600 ELSE 601
600 GOSUB 670
    :GOTO525
601 IF ASC(A$)=46 THEN GOSUB 50 ELSE 618
602 GOTO 525
618 GOTO586
619 RETURN
    :END
620 '***************************************************
622 'LINEPRINTER OUTPUT ROUTINE
623 IF R=0 OR C=0 THEN RETURN
624 AN$="DATA SET NAME --> "
    :CLS
    :PRINT@448,"PRESS <ENTER> WHEN PRINTER IS READY.";
    :INPUT AN
    :T$=LEFT$(F$,LEN(F$)-1)
    :T$=AN$+T$
    :GOSUB42000
    :LPRINT TAB(ZZ);T$
    :LPRINT " "
    :LPRINT " "
630 JJ=INT(C/4.1+1)
    :II=INT(R/200.1+1)
632 FORI=1TOII
634 IFR-200*I>=0.0THENN=200ELSEN=200+(R-200*I)
636 FORJ=1TOJJ
638 IFC-4*J>=0.0THENL=4ELSE L=4+(C-4*J)
640 LPRINT"COL:";
    :FORKK=0TO(L-1)
    :LPRINT TAB(14*KK+3) N$((KK+1)+4*(J-1));
642 NEXT KK
644 LPRINT" "
646 LPRINT"--------------------------------------------------------------"
648 FOR M=1TON
650 LPRINT "R";M+200*(I-1);":";
652 FOR K=1TO L
654 A=A(M+200*(I-1),K+4*(J-1))
656 LPRINT TAB(14*(K-1)+8) A;
658 NEXT K
660 LPRINT
662 NEXT M
664 LPRINT " "
    :LPRINT " "
    :LPRINT " "
666 NEXT J,I
668 RETURN
670 '***********************************
671 'SCREEN PRINT ROUTINE-  ACTIVATED BY PROGRAMMED "@" ASC(64)
672 '/////////////////
673 IF PEEK(14312)<>63 THEN RETURN
674 LPRINT STRING$(64,"+")
675 FOR N= 15360 TO 16383 STEP 64
676 A$=" "
679 FOR Q=0TO63
680 Z=PEEK(N+Q)
    :IFZ>0ANDZ<27THENZ=Z+64ELSEIFZ<32THENZ=32
681 IFZ>=127 AND Z<=191 THEN Z=42
682 B$=CHR$(Z)
683 A$=A$+B$
684 NEXT Q
685 IF PEEK(14312)<>63THEN RETURN
686 LPRINT " "
    :LPRINT A$
687 NEXT N
688 LPRINT STRING$(64,"+")
689 FORN=1TO3
    :LPRINT "  "
    :NEXT
690 RETURN
695 RUN"GLR/BAS"
    :END
700 '***************************************************
710 'GENERALIZED I/O SUBROUTINES FOR PROGRAM STARTERS
720 '/////////////////
735 CLS
    :T$="NORTHERN HARDWOODS LABORATORY, USFS, MARQUETTE, MI"
    :GOSUB42000
736 T$="///////////////////////////////////////////////////////"
    :GOSUB42000
737 PRINT
738 T$="MENU FOR:  GENERAL LINEAR REGRESSION ANALYSIS SYSTEM
739 GOSUB42000
742 T$="PART II.  CONFIDENCE INTERVALS AND ERROR ANALYSIS"
    :GOSUB42000
    :PRINT
    :IFTX=-1THENGOSUB40000ELSE750
750 TX=1
    :PRINT"  1.  RETURN TO MAIN MENU          2.  GOTO BASIC
760 PRINT"  3.  READ A MATRIX FROM DISK     4.  WRITE A MATRIX TO DISK
770 PRINT"  5.  ENTER A MATRIX MANUALLY     6.  DISPLAY MATRIX ON VIDEO
780 PRINT"  7.  PRINT MATRIX                8.  CONFDNCE INTERVALS FOR B
790 PRINT"  9.  CONFDNCE INTVLS FOR YHAT    10.  PLOT RESIDUALS
800 PRINT" 11.  MULTICOLLINEARITY CHECK     12.  HETEROSCEDASTICITY CHECK"
810 PRINT" 13.  AUTOCORRELATION CHECK       14.  SCALED B
820 PRINT" 15.  EQUALITY OF REG. LINES"
900 PRINT
    :PRINT"SELECT ONE OF THE ABOVE --> ";
    :FL=-2
    :GOSUB15
    :AN=VAL(IN$)
    :IFAN<=0ORAN>16THEN740
905 IFAN<8THENFM$="FALSE"
    :'PREVENTS DATA MIXUPS
```

```
910 ON AN GOSUB 695,43000,125,220,340,510,620,1000,2000,3000,4000,5000,6000,7000
8000
920 GOTO 735
1000 '********************************************
1010 'CONFIDENCE INTERVALS FOR COEFFICIENTS B
1020 '//////////////////////
1030 IFFM$="FALSE"THENGOSUB 10000
    :'READ B,Y, AND (X'X)-1
1040 GOSUB11000
    :'GET TC2
1050 SIG=SQR(B(N+1))
    :FORI=1TON
    :CI(I)=SIG*TC2*SQR(XI(I,I))
    :NEXTI
    :IFA(1,1)=1ANDA(M,1)=1THENLL=0ELSELL=1
1060 CLS
    :PRINT@10,"CONFIDENCE INTERVALS FOR THE COEFFICIENTS."
    :PRINT"T-VALUE FOR 95% CONFIDENCE INTERVAL= ";TC2;" DF= "X
    :PRINT"COEFFICIENT","UPPER LEVEL","LOWER LEVEL","STAND. DEV."
1062 PRINT"------------------------------------------------------------"
1065 K=1
    :FORI=1TON
    :IFLL=0THENK=I-1
1070 PRINT"B"K" ";B(I),B(I)+CI(I),B(I)-CI(I),SQR(XI(I,I)*B(N+1))
    :K=K+1
    :NEXTI
1080 GOSUB8130
1090 RETURN
2000 '**************************************************
2010 'CONFIDENCE INTERVAL AROUND PREDICTED Y VALUES
2020 '/////////////////////
2030 CN=0
    :IFFM$="FALSE"THENGOSUB10000
    :'CHECK IF Y AND (X'X)-1 ARE LOADED
2040 GOSUB11000
    :'FILL TC2
2045 SIG=SQR(B(N+1))
    :GOTO2055
2050 CLS
    :PRINT@10,"CONFIDENCE INTERVALS FOR PREDICTED Y VALUES."
    :PRINT"T-VALUE FOR 95% TWO-SIDED CONFIDENCE INTERVAL= ";TC2;" DF= "X
    :PRINT"YHAT","UPPER CI","LOWER CI","STAND. ERR."
2052 PRINT"------------------------------------------------------------"
    :RETURN
2055 GOSUB2050
2060 FORI=1TOM
    :SY=0
    :VY=0
    :FORJ=1TON
    :CI(J)=0
    :FORK=1TON
    :CI(J)=CI(J)+A(I,K)*XI(K,J)
    :NEXTK,J
2070 FORJ=1TON
    :VY=VY+CI(J)*A(I,J)
    :NEXTJ
    :SY=SIG*SQR(VY)
    :CI=TC2*SY
2080 PRINTY(I,2),Y(I,2)+CI,Y(I,2)-CI,SY
2085 Y(I,5)=Y(I,2)+CI
```

```
     :Y(I,6)=Y(I,2)-CI
2090 IFCN<9THENCN=CN+1ELSE2110
2100 GOTO2120
2110 GOSUB8130
2115 CN=0
     :GOSUB2050
2120 NEXTI
2125 A$=INKEY$
     :IFA$=""THEN2125
2127 CLS
     :PRINT@448,"DO YOU WISH TO SAVE THE CONFIDENCE INTERVALS FOR YHAT IN THE Y  M
ATRIX? (Y/N) --> ";
     :FL=1
     :GOSUB15
     :IFIN$="N"THENRETURNELSE2130
2130 DD$="1"
     :F$="Y"
     :C=6
     :R=M
     :FORI=1TOM
     :FORJ=1TOC
     :A(I,J)=Y(I,J)
     :NEXTJ,I
     :FORI=1TO4
     :N$(I)=YN$(I)
     :NEXTI
     :N$(5)="Y-UPPER"
     :N$(6)="Y-LOWER"
     :GOSUB222
     :RETURN
3000 '*************************************
3010 'PREPARE THE Y MATRIX FOR PLOTTING OF RESIDUALS
3020 '//////////////////////
3022 CLS
     :T$="PREPARING FOR MATRIX PLOTTING OF RESIDUALS"
     :GOSUB42000
3030 F$="Y"
     :GOSUB135
     :FORI=1TOR
     :FORJ=1TOC
     :Y(I,J)=A(I,J)
     :NEXTJ,I
     :FORI=1TO6
     :YN$(I)=N$(I)
     :NEXTI
     :F$="X"
     :GOSUB135
3040 N=C
     :C=6
     :FORJ=1TON
     :IFA(1,J)=1ANDA(R,J)=1THEN3060
3050 C=C+1
     :FORI=1TOR
     :Y(I,C)=A(I,J)
     :NEXTI
     :N$(C)="X"+STR$(C-6)
3060 NEXTJ
3062 C=C+1
     :FORI=1TOR
     :Y(I,C)=I
```

```
    :NEXTI
    :N$(C)="OBS #"
3065 FORI=1TO6
    :N$(I)=YN$(I)
    :NEXTI
    :'NOTE X'S LABELED ABOVE
3070 DD$="1"
    :F$="Y"
    :FORI=1TOM
    :FORJ=1TOC
    :A(I,J)=Y(I,J)
    :NEXTJ,I
    :GOSUB222
3080 RUN"MULTPLT/BAS"
4000 '*******************************************
4010 'MULTICOLLINEARITY CHECK
4020 '/////////////////////
4021 CLS
    :T$="CHECK FOR MULTICOLLINEARITY"
    :GOSUB42000
    :PRINT
4022 IFFM$="TRUE"THEN4035
4025 F$="B"
    :GOSUB135
    :FORI=1TOR
    :B(I)=A(I,1)
    :NEXTI
    :N=B(R)
4035 IFB(N+3)<NTHENZI$="REDUCED RANK"ELSEZI$="FULL RANK"
4040 PRINT
    :PRINT"RANK(X)= "B(N+3);
    :PRINT"  X HAS "ZI$
4050 PRINT"MAXIMUM SINGULAR VALUE (X) = "B(N+5)
    :IFB(N+6)=-1THENZI=0ELSEZI=B(N+6)
4060 PRINT"MINIMUM SINGULAR VALUE (X) = "ZI
4070 IFB(N+6)=-1THENZI$="INFINITE"ELSEZI$=STR$(B(N+5)/B(N+6))
4080 PRINT"CONDITION NUMBER FOR (X) = "ZI$
4090 PRINT"COLLINEARITY NUMBER FOR (X) = "1/B(N+4)
    :PRINT
    :PRINT
4100 PRINT"IF CONDITION NUMBER IS CLOSE TO 1, THEN X = INDEPENDENT (NONSINGULAR).
"

4110 PRINT"IF CONDITION NUMBER IS INFINITE THEN X = DEPENDENT (SINGULAR)."
4120 PRINT"IF CONDITION NUMBER CLOSE TO COLLINEARITY NUMBER, X = NEARLY DEPENDENT
 (SINGULAR)."
4130 GOSUB8130
4140 RETURN
5000 '*******************************************
5010 'HETEROSCEDASTICITY CHECK
5020 '//////////////////////
5030 CLS
    :PRINT@448,"NO NUMERICAL EVALUATION IMPLEMENTED AT PRESENT."
    :PRINT"VISUAL EXAMINATION OF RESIDUALS PLOTS IS RECOMMENDED."
5035 A$=INKEY$
    :IFA$=""THEN5035
5040 RETURN
6000 '*****************************************
6010 'AUTOCORRELATION CHECK
6020 '/////////////////////
6025 CLS
```

```
    :T$="AUTOCORRELATION CHECK"
    :GOSUB42000
    :PRINT
6030 IFFM$="TRUE"THEN6045
6045 F$="Y"
    :GOSUB135
6050 S1=0
    :S2=0
    :FORI=2TOR
    :S1=S1+(A(I,4)-A(I-1,4))[2
    :S2=S2+A(I,4)*A(I,4)
    :NEXTI
    :S2=S2+A(1,4)*A(1,4)
6060 PRINT"THE DURBIN-WATSON STATISTIC:  D= "S1/S2
6070 PRINT
    :PRINT"SEE USER'S GUIDE FOR EVALUATION."
6080 GOSUB8130
6090 RETURN
7000 '********************************************
7010 'PRODUCE THE SCALED B VALUES
7020 '///////////////////
7030 CLS
    :T$="SCALED B COEFFICIENTS"
    :GOSUB42000
    :PRINT
7033 IF FM$="FALSE"THENGOSUB10000
    :GOTO7040
    :ELSE7035
7035 F$="X"
    :GOSUB135
    :'NEED X MATRIX IN A() FOR TEST IN 7040
7040 IFA(1,1)=1ANDA(M,1)=1THENLL=2ELSELL=1
7050 FORI=LLTON
    :C(I)=0
    :XZ(I)=0
    :NEXTI
7060 FORI=1TOM
    :FORJ=LLTON
    :CI(J)=CI(J)+A(I,J)
    :NEXTJ,I
    :'COL SUMS
7070 FORJ=LLTON
    :CI(J)=CI(J)/M
    :NEXTJ
    :'COL AVGS
7080 SYY=0
    :FORI=1TOM
    :SYY=SYY+(Y(I,1)-B(N+7))[2
    :FORJ=LLTON
    :XZ(J)=XZ(J)+(A(I,J)-CI(J))[2
    :NEXTJ,I
7090 K=1
    :FORI=LLTON
    :IFLL=2THENK=I-1
7100 PRINT"B"K" SCALED = "B(I)*SQR(XZ(I)/SYY)
7110 K=K+1
    :NEXTI
7120 GOSUB8130
7130 RETURN
8000 '***************************************************
```

```
8010 'TEST FOR EQUALITY OF REGRESSION LINES
8020 '////////////////////////
8022 CLS
    :PRINT"YOU MUST BE PREPARED TO ENTER THE FOLLOWING INFORMATION"
    :PRINT
    :PRINT"1.  THE B(I) VALUE FOR EVERY EQUATION"
    :PRINT"2.  ITS STANDARD DEVIATION"
    :PRINT"3.  THE ERROR SUM OF SQUARES FOR EACH EQUATION."
8024 PRINT"4.  THE ERROR DEGREES OF FREEDOM FOR EACH EQUATION ."
    :PRINT
    :PRINT"IF YOU HAVE THE ABOVE DATA PIECES FOR EACH EQUATION TO BE"
    :PRINT"COMPARED THEN ENTER <Y>.  IF NOT ENTER <N> AND YOU WILL BE"
8026 PRINT"RETURNED TO THE MENUE PART II. TO COMPUTE THE ABOVE INFORMATION."
    :PRINT
    :PRINT"ENTER --> ";
    :FL=1
    :GOSUB15
    :IFIN$="Y"THEN8028ELSERETURN
8028 CLS
    :PRINT@448,"HOW MANY EQUATIONS ARE TO BE COMPARED? --> ";
    :FL=-2
    :GOSUB15
    :K=VAL(IN$)
    :PRINT
    :R=K
    :C=4
    :N$(1)="B"
    :N$(2)="STAND.DEV."
    :N$(3)="ERROR SS"
    :N$(4)="ERROR DF"
8040 CLS
    :PRINT"PLEASE ENTER THE REQUESTED INFORMATION FOR EACH EQUATION."
    :PRINT
    :FORI=1TOK
    :PRINT"EQUATION #"I"
8050 PRINT"VALUE OF B COEFFICIENT --> ";
    :FL=-10
    :GOSUB15
    :A(I,1)=VAL(IN$)
    :PRINT
    :PRINT"STANDARD DEVIATION OF B --> ";
    :GOSUB15
    :A(I,2)=VAL(IN$)
    :PRINT
    :PRINT"ERROR SUM OF SQARES --> ";
    :GOSUB15
    :A(I,3)=VAL(IN$)
    :PRINT
8060 PRINT"ERROR DEGREES OF FREEDOM --> ";
    :GOSUB15
    :A(I,4)=VAL(IN$)
    :PRINT
    :CLS
    :NEXTI
8062 CLS
    :PRINT@448,"WISH TO REVIEW THE INPUT? (Y/N) --> ";
    :FL=1
    :GOSUB15
    :IFIN$="Y"THENGOSUB510
8063 FORI=1TOR
```

```
    :A(I,2)=A(I,2)*A(I,2)
    :NEXTI
8065 CLS
    :PRINT@448,"CONTINE <C> OR REDO INPUT <R> --> ";
    :GOSUB15
    :IFIN$="C"THEN8067ELSE8040
8067 CLS
    :PRINT"ARE THE VARIANCES ASSUMED HOMOGENEOUS <O> OR"
    :PRINT"HETEROGENEOUS <E> ? --> ";
    :FL=1
    :GOSUB15
    :IFIN$="O"THEN8068ELSEIFIN$="E"THEN8200ELSE8067
8068 CLS
    :PRINT@458,"PLEASE BE PATIENT.  COMPUTATIONS IN PROGRESS."
8070 K=R
    :S1=0
    :S2=0
    :FORI=1TOK
    :S1=S1+A(I,3)
    :S2=S2+A(I,4)
    :A(I,2)=(A(I,3)/A(I,4))/A(I,2)
    :NEXTI
    :M1=S1/S2
    :ES=S1
    :DD=S2
8080 S1=0
    :S2=0
    :FORI=1TOK
    :S1=S1+A(I,1)*A(I,2)
    :S2=S2+A(I,2)
    :NEXTI
    :BB=S1/S2
8090 S1=0
    :FORI=1TOK
    :S1=S1+((A(I,1)-BB)*(A(I,1)-BB))/(1/A(I,2))
    :NEXTI
    :SB=S1
    :DN=K-1
    :M2=SB/DN
    :FR=M2/M1
    :GOSUB20000
8100 CLS
    :PRINT"RESULTS OF THE TEST FOR EQUALITY OF REGRESSION COEFFICIENTS."
    :PRINT
    :PRINT"WEIGHTED AVERAGED B = "BB
    :PRINT"SUM OF SQUARES FOR COMBINED B'S = "SB
8110 PRINT"NUMERATOR DEGREES OF FREEDOM = "DN
    :PRINT"MEAN SQUARE FOR B'S = "M2
    :PRINT"COMBINED ERROR SUM OF SQUARES = "ES
    :PRINT"DENOMINATOR DEGREES OF FREEDOM = "DD
    :PRINT"COMBINED ERROR MEAN SQUARE = "M1
8120 PRINT"THE CALCULATED F-VALUE = "FR
    :PRINT"THE PROBABILITY OF REJECTING THE NULL HYPOTHESIS = "FB
8130 A$=INKEY$
    :IFA$=""THEN8130ELSEIFASC(A$)=64THENGOSUB670
8140 RETURN
8200 'HETEROGENEOUS VARIANCES
8210 CLS
    :PRINT@448,"PLEASE BE PATIENT.  COMPUTATIONS IN PROGRESS."
8220 ES=0
```

```
    :DD=0
    :K=R
    :FORI=1TOK
    :ES=ES+A(I,3)
    :DD=DD+((A(I,3)*A(I,3))/A(I,4))
    :NEXTI
    :DD=INT((ES*ES)/DD)
    :M1=ES/DD
8230 S1=0
    :S2=0
    :FORI=1TOK
    :S1=S1+A(I,1)/A(I,2)
    :S2=S2+1/A(I,2)
    :NEXTI
    :BB=S1/S2
    :SB=0
    :FORI=1TOK
    :SB=SB+((A(I,1)-BB)*(A(I,1)-BB))/A(I,2)
    :NEXTI
    :SB=SB*M1
    :DN=K-1
    :M2=SB/DN
    :FR=M2/M1
    :GOSUB20000
    :GOTO8100
10000 CLS
    :PRINT@448,"MATRICES B, Y, X AND (X'X)-1 WILL NOW BE READ FROM DISK."
    :F$="B"
    :GOSUB135
    :FORI=1TOR
    :B(I)=A(I,1)
    :NEXTI
    :N=B(R)
    :F$="Y"
    :GOSUB135
    :FORI=1TOR
    :FORJ=1TOC
    :Y(I,J)=A(I,J)
    :NEXTJ,I
    :M=R
10010 FORI=1TO6
    :YN$(I)=N$(I)
    :NEXTI
    :F$="XPXI"
    :GOSUB135
    :FORI=1TON
    :FORJ=1TON
    :XI(I,J)=A(I,J)
    :NEXTJ,I
    :F$="X"
    :GOSUB135
    :FM$="TRUE"
    :RETURN
11000 '*********************************
11010 'INTERPOLATION FOR T C2 VALUES
11020 '///////////////////////
11025 IFXT(1)<>0THEN11050
11030 DATA 1,12.706,2,4.303,3,3.182,4,2.776,5,2.571,6,2.447,7,2.365,8,2.306,9,2.
62,10,2.228,15,2.131,20,2.086,25,2.060,30,2.042,40,2.021,60,2.00,120,1.98
11040 FORI=1TO17
```

```
    :READXT(I),YT(I)
    :NEXTI
11050 X=M-B(N+3)
    :IFX<XT(1)THENTC2=YT(1)ELSEIFX>XT(17)THENTC2=YT(17)ELSE11070
11060 RETURN
11070 FORI=2TO17
    :IFX<=XT(I)THEN11080ELSENEXTI
11080 TC2=(YT(I)-YT(I-1))/(XT(I)-XT(I-1))*(X-XT(1-1))+YT(I-1)
11090 RETURN
20000 '*************************************
20010 'SUBROUTINE   FPROB
20020 'INPUT
    : FR=R RATIO  DN=NUMERATOR DF   DD=DENOMINATOR DF
20030 'OUTPUT
    : FB= PROBABILITY OF F
20040 '//////////////////////
20050 X#=1
    :IFFR<1THEN20070
20060 S#=DN
    :T#=DD
    :ZZ#=FR
    :GOTO20080
20070 S#=DD
    :T#=DN
    :ZZ#=1/FR
20080 J5=2/9/S#
    :K5=2/9/T#
    :Z#=K5*ZZ#[(2/3)+J5
    :GOSUB20150
    :Y#=ABS((1-K5)*ZZ#[(1/3)-1+J5)/Z3#
    :IFT#<4THEN20100
20090 X#=.5/(1+Y#*(.196854+Y#*(.115194+Y#*(.000344+Y#*.019527))))[4
    :X#=INT(X#*10000+.5)/10000
    :GOTO20110
20100 Y#=Y#*(1+.08*Y#[4/T#[3)
    :GOTO20090
20110 IFF#>1THEN20130
20120 X#=1-X#
20130 FB=1-X#
20140 RETURN
20150 Z3#=SQR(Z#)
    :Z3#=(Z3#+Z#/Z3#)/2
    :Z3#=(Z3#+Z#/Z3#)/2
    :RETURN
40000 M=200
    :N=11
    :DIM N$(N),A(M,N),B(N+3),Y(M,N),CI(N),XT(17),YT(17),XI(N,N),YN$(6),XZ(N)
40015 MV=-99.99
    :FM$="FALSE"
40020 RETURN
42000 CC=LEN(T$)
    :ZZ=INT(30-CC/2)
    :PRINT TAB(ZZ);T$
    :RETURN
    :'CENTERING ROUTINE
43000 END
```

APPENDIX III. Source code listing for program MULPPLT/BAS

```
1 CLS
    :CLEAR550
    :PRINT"MULTIPLE PLOT ROUTINE VERSION 8-24-80"
    :PRINT"NORTHERN HARDWOODS LABORATORY, USFS, MARQUETTE, MI."
    :GOSUB4000
    :PRINT
    :GOTO33
2 IN$=""
    :W$=INKEY$
    :WD=0
    :WS=WD
    :WL%=WD
    :IFFL=WDTHENFL=1
3 PRINTSTRING$(ABS(FL),CHR$(136));STRING$(ABS(FL),CHR$(24)
);
4 PRINTCHR$(14);
    :FORW%=1TO25
    :W$=INKEY$
    :IFW$<>""THEN5
ELSENEXT
    :PRINTCHR$(15);
    :FORW%=1TO25
    :W$=INKEY$
    :IFW$<>""THEN5
ELSENEXT
    :GOTO4
5 IFW$<>CHR$(13)THEN7ELSEPRINTSTRING$(ABS(FL)-WL%," "
);
6 PRINTCHR$(15);
    :W%=25
    :NEXT
    :RETURN
7 PRINTCHR$(14);
    :IFW$=CHR$(24)THENPRINTSTRING$(WL%,CHR$
(24));
    :GOTO2
8 IFW$<>CHR$(8)THEN12ELSEIFWL%=0THEN4ELSEPRINTCHR$(24);
    :IFFL>0THEN10ELSEIFPEEK(16418)=44THEN11
9 IFPEEK(16418)=46THENWD=0
    :GOTO10ELSEIFPEEK(16418)=43
ORPEEK(16418)=45THENWS=0
10 IN$=LEFT$(IN$,LEN(IN$)-1)
11 WL%=WL%-1
    :POKE16418,136
    :GOTO4
12 IFABS(FL)=WL%THEN4ELSEIFFL>0THENIFW$>=" "ANDW$<=
"Z"THEN17
13 IFW$="."ANDWD=0THENWD=1
    :GOTO17
14 IFW$=","THENPRINTW$;
    :WL%=WL%+1
    :GOTO18
15 IF(W$="-"ORW$="+")ANDWS=0ANDWL%=0THENWS=1
    :GOTO17
16 IFW$<"0"ORW$>"9"THEN4
17 PRINTW$;
    :IN$=IN$+W$
    :WL%=WL%+1
18 IFABS(FL)=1THEN6ELSE4
19 CLS
```

```
    :PRINT@448,"INSERT DATA DISK <ENTER> FILENAME OF DESIRED DATA SET --> ";
    :INPUTF$
    :FJ$=F$
    :FF$=F$+"N"
    :F$=F$+"M"
    :G$=FJ$+"L"
    :OPEN"I",1,FF$
    :INPUT#1,R,C
    :CLOSE1
    :GOSUB130
    :OPEN"I",1,F$
    :FORI=1TOR
    :FORJ=1TOC
    :INPUT#1,A(I,J)
    :NEXTJ,I
    :CLOSE1
20 OPEN"I",1,G$
    :FORI=1TOC
    :INPUT#1,N$(I)
    :NEXT
    :CLOSE
    :RETURN
21 CLS
    :PRINT@448,"INSERT DATA DISK <ENTER> FILENAME OF NEW DATA SET --> ";
    :INPUTF$
    :FJ$=F$
    :PRINT
    :PRINT"ENTER DISK DRIVE # WHERE DATA SHOULD BE SAVED --> ";
    :INPUTDD$
    :FF$=F$+"N:"+DD$
    :F$=F$+"M:"+DD$
    :G$=FJ$+"L:"+DD$
22 OPEN"O",1,FF$
    :PRINT#1,R;C;
    :CLOSE
    :OPEN"O",1,F$
    :
23 FORI=1TOR
    :FORJ=1TOC
    :PRINT#1,A(I,J);
    :NEXTJ,I
    :CLOSE1
    :OPEN"O",1,G$
    :FORI=1TOC
    :PRINT#1,STR$(I);",";
    :NEXT
    :CLOSE
    :RETURN
24 END
25 REM
26 CLS
    :JJ=INT(C/4.1+1)
    :II=INT(R/13.1+1)
    :
    :
    :FORI=1TOII
    :
    :IFR-13*I>=0.OTHENN=13ELSEN=13+(R-13*I)
27 FORJ=1TOJJ
    :
```

```
    :IFC-4*J>=0.0THENL=4ELSEL=4+(C-4*J)
28 CLS
    :PRINT"VAR:";
    :FORKK=0TO(L-1)
    :PRINTTAB(14*KK+8)(KK+1)+4*(J-1);
    :NEXTKK
    :PRINT
    :PRINT"------------------------------------------------------------------"
    :FORM=1TON
    :PRINT"O";M+13*(I-1);":";
    :FORK=1TOL
    :A=A(M+13*(I-1),K+4*(J-1))
29 PRINTTAB(14*(K-1)+8)A;
    :NEXTK
    :PRINT
    :NEXTM
30 A$=INKEY$
    :IFA$="" GOTO30
31 NEXTJ,I
    :
    :
    :
    :
    :RETURN
32 END
33 GOSUB124
34 PRINT@448,"PLEASE ENTER: "
    :PRINT"MATRIX OF INPUT DATA FROM (1) DISK (2)  FUNCTION --> ";
    :FL=-1
    :GOSUB2
    :B=VAL(IN$)
    :IFB=0ORB>2THEN34
35 IFB=1GOSUB19ELSEGOSUB119
36 CLS
    :PRINT@448,"PLEASE ENTER: DISPLAY MATRIX ON VIDEO? (Y/N) -> ";
    :FL=1
    :GOSUB2
    :Q=(IN$="Y")OR(IN$="N")
    :IFQ=0GOTO36
37 IFIN$="Y"THENGOSUB26
38 CLS
    :PRINT
    :PRINT
    :PRINT
    :PRINT
    :PRINT"DO YOU WANT TO SEE VAR. #'S AND LABELS (Y/N) -->";
    :FL=1
    :GOSUB2
    :IFIN$="Y"GOSUB127ELSE39
39 CLS
    :PRINT@192,"PLEASE DESIGNATE X-AXIS VARIABLE  # --> ";
    :FL=-2
    :GOSUB2
    :ZX=VAL(IN$)
    :IFZX=0ORZX>CTHEN39ELSEPRINT
40 PRINT"HOW MANY VARIABLES WILL BE PLOTTED ON Y-AXIS (<=6) --> ";
    :FL=-1
    :GOSUB2
    :NI=VAL(IN$)
    :IFNI=0ORNI>6GOTO40
```

```
41 FORCI=1TONI
   :PRINT
42 PRINT"DESIGNATE VARIABLE  # FOR DEPENDENT VARIABLE ";CI;" --> ";
   :FL=-2
   :GOSUB2
   :IW(CI)=VAL(IN$)
   :IFIW(CI)=0ORIW(CI)>CTHEN42
43 NEXTCI
44 CLS
   :PRINT@448,"IS THE MATRIX ALREADY SORTED ON THE X-AXIS (Y/N)? --> ";
   :FL=1
   :GOSUB2
   :IFIN$="Y"THENGOSUB99ELSEIFIN$="N"THEN46ELSE44
45 GOTO65
46 CLS
   :PRINT@458,"PLEASE BE PATIENT.  SORTING IN PROGRESS."
   :YL=9999
   :YH=-9999
   :M=R
47 M=INT(M/2)
   :IFM=0THEN58
48 J=1
   :K=R-M
49 I=J
50 L=I+M
   :FORCI=1TONI
   :ZY=IW(CI)
   :IFA(I,ZY)=-99.99THEN53
51 IFYL>A(I,ZY)THENYL=A(I,ZY)
52 IFYH<A(I,ZY)THENYH=A(I,ZY)
53 NEXTCI
   :IFA(I,ZX)<=A(L,ZX)THEN56
54 FORJJ=1TOC
   :T(JJ)=A(I,JJ)
   :A(I,JJ)=A(L,JJ)
   :A(L,JJ)=T(JJ)
   :NEXTJJ
   :I=I-M
   :IFI<1THEN56
55 GOTO50
56 J=J+1
   :IFJ>KTHEN47
57 GOTO49
58 XL=A(1,ZX)
   :XH=A(R,ZX)
59 IFI>=RTHENGOTO63
60 I=I+1
   :FORCI=1TONI
   :ZY=IW(CI)
   :IFYL>A(I,ZY)THENYL=A(I,ZY)
61 IFYH<A(I,ZY)THENYH=A(I,ZY)
   :NEXTCI
62 GOTO59
63 CLS
   :PRINT@448,"PLEASE ENTER: DISPLAY SORTED MATRIX ON VIDEO (Y/N) ? --> ";
   :FL=1
   :GOSUB2
   :IFIN$="Y"GOSUB26ELSEIFIN$="N"THEN64ELSE63
64 PRINT
   :PRINT"PLEASE ENTER:  SAVE SORTED MATRIX (Y/N) ? --> ";
```

```
    :FL=1
    :GOSUB2
    :IFIN$="Y"GOSUB21ELSEIFIN$="N"GOTO65ELSE64
65 REM
66 CLS
    :T$="GRAPHING STATUS MENU"
    :CC=LEN(T$)
    :GOSUB126
    :PRINTTAB(ZZ);T$
    :PRINT
    :PRINT"  1.  X-VARIABLE = VAR. #";ZX
    :PRINT"  2.  Y-VARIABLE = VAR. #";
    :FORCI=1TONI
    :PRINTIW(CI);
    :NEXTCI
    :PRINT" "
67 PRINT"  3.  RANGE OF X-VARIABLE  --> ";XL;" TO ";XH
    :PRINT"  4.  RANGE OF Y-VARIABLE  --> ";YL;" TO ";YH
    :IFZV=1THENZV$="ON"ELSEZV$="OFF"
68 IFZH=1THENZH$="ON"ELSEZH$="OFF"
69 PRINT"  5.  VERTICAL CONTROL LINE STATUS --> ";ZV$
    :PRINT"  6.  HORIZONTAL CONTROL LINE STATUS --> ";ZH$
    :PRINT"  7.  TITLE OF GRAPH --> ";Z0$
    :PRINT"  8.  X-AXIS LABEL --> ";W1$
    :PRINT"  9.  Y-AXIS LABEL --> ";W0$
70 PRINT" 10.  EXECUTE THE GRAPHING ROUTINE"
    :PRINT" 11.  GET ANOTHER MATRIX                   12. REGRESSION PART II
71 PRINT" 13.  DISPLAY MATRIX                     14. PRINT DATA MATRIX"
72 PRINT
    :PRINT"SELECT STATUS CHANGES OR CONTINUATION --> ";
    :FL=-2
    :GOSUB2
    :AN=VAL(IN$)
    :IFAN<=0ORAN>14THEN72
73 ONANGOTO39,39,103,104,105,107,109,110,111,75,132,112,113,114
74 GOTO66
75 CLS
    :PRINT@448,"PRESS <ENTER> WHEN PRINTER IS READY.";
    :INPUTAN
    :I=1
    :J=ZX
    :Z5=XL
    :Z6=XH
    :Z1=YL
    :Z2=YH
    :Z0(13)=Z1
    :Z0(14)=(Z2-Z1)/5.0
    :Z7=INT(30-LEN(Z0$)/2)
    :Z8=INT(30-LEN(W0$)/2)
    :Z9=INT(30-LEN(W1$)/2)
    :LPRINTTAB(Z7);Z0$
    :LPRINT" "
76 LPRINTTAB(Z8);W0$
    :LPRINTTAB(Z9);W1$
    :LPRINT
    :LPRINTTAB(6);
    :FORZ8=0TO5
    :Z0(15)=Z0(13)+Z0(14)*Z8
    :LPRINTUSING"+#.##EEEE";Z0(15);
    :IFZ8<5THENLPRINT" ";
```

```
77 NEXTZ8
    :Z0(14)=(Z2-Z1)/50
    :LPRINT
    :Z0(11)=(Z6-Z5)/50
    :Z7=1
    :FORI8=0TO52
    :FORZ9=0TO52
    :Z1$(Z9)=" "
    :NEXTZ9
    :IFI8=0GOTO95
78 IF I8=52GOTO88
79 IF Z7>0GOTO86
80 IF I8=1THENGOTO82
81 IF ZV=0THENGOTO83
82 FORZ9=3TO51STEP2
    :Z1$(Z9)="-"
    :NEXTZ9
83 FORZ9=1TO51STEP10
    :IFI8=1THENGOTO85
84 IFZ9<>1ANDZH=0ANDZV=0THENGOTO88
85 Z1$(Z9)="+"
    :NEXTZ9
    :GOTO88
86 FORZ9=1TO51STEP10
    :IFZH=0ANDZ9<>1THENGOTO88
87 Z1$(Z9)="!"
    :NEXTZ9
88 IF I>RTHENGOTO95
89 IFXL>A(I,J)THENGOTO94
90 IF Z5+(I8-1)*Z0(11)<A(I,J)THENGOTO95
91 FORCI=1TONI
    :J=IW(CI)
    :IFA(I,J)=-99.99THEN93
92 Z1$(INT(1.5+(A(I,J)-Z1)*50/(Z2-Z1)))=WF$(CI)
93 NEXTCI
94 I=I+1
    :J=ZX
    :GOTO88
95 IF Z7>0GOTO97
96 Z0(12)=Z5+Z0(11)*(I8-1)
    :LPRINTUSING"+#.##EEEE";Z0(12);
    :Z7=5
    :GOTO98
97 LPRINT"             ";
98 FORZ9=0TO52
    :LPRINTZ1$(Z9);
    :NEXTZ9
    :LPRINT
    :Z7=Z7-1
    :NEXTI8
    :Z1=Z1+1
    :Z0(0)=55
    :GOTO66
99 XL=A(1,ZX)
    :XH=A(R,ZX)
    :YL=9999
    :YH=-9999
    :FORI=1TOR
    :FORCI=1TONI
    :ZY=IW(CI)
    :IFA(I,ZY)=-99.99THEN102
100 IFYL>A(I,ZY)THENYL=A(I,ZY)
101 IFYH<A(I,ZY)THENYH=A(I,ZY)
102 NEXTL1
    :NEXTI
    :RETURN
103 XL(1)=XL
    :XH(1)=XH
    :CLS
    :PRINT@448,"PLEASE ENTER NEW MINIMUM VALUE FOR X --> ";
    :FL=-12
    :GOSUB2
    :XL=VAL(IN$)
    :PRINT
    :PRINT"PLEASE ENTER NEW MAXIMUM VALUE FOR X --> ";
    :GOSUB2
    :XH=VAL(IN$)
    :GOTO66
104 YL(1)=YL
    :YH(1)=YH
    :CLS
    :PRINT@448,"PLEASE ENTER NEW MINIMUM VALUE OF Y --> ";
    :FL=-12
    :GOSUB2
    :YL=VAL(IN$)
    :PRINT
    :PRINT"PLEASE ENTER NEW MAXIMUM VALUE OF Y --> ";
    :GOSUB2
    :YH=VAL(IN$)
    :GOTO65
105 IFZV=1THENZV=0ELSEZV=1
106 GOTO65
107 IFZH=1THENZH=0ELSEZH=1
108 GOTO66
109 CLS
    :PRINT@448,"PLEASE ENTER NEW TITLE --> "
    :FL=50
    :GOSUB2
    :Z0$=IN$
    :GOTO66
110 W1$="X-AXIS:   "
    :CLS
    :PRINT@448,"PLEASE ENTER NEW X-AXIS LABEL --> "
    :FL=50
    :GOSUB2
    :W1$=W1$+IN$
    :GOTO66
111 W0$="Y-AXIS:   "
    :CLS
    :PRINT@448,"PLEASE ENTER NEW Y-AXIS LABEL --> "
    :FL=50
    :GOSUB2
    :W0$=W0$+IN$
    :GOTO66
112 RUN"GLR1/BAS"
113 GOSUB25
    :GOTO66
114 GOSUB133
    :AN$="DATA SET NAME --> "
    :CLS
    :PRINT@448,"PRESS <ENTER> WHEN PRINTER IS READY.";
    :INPUTAN
    :DN$=LEFT$(F$,LEN(F$)-1)
    :DN$=AN$+DN$
    :CC=LEN(DN$)
    :GOSUB126
    :LPRINTTAB(ZZ);DN$
    :LPRINT" "
    :LPRINT" "
    :JJ=INT(C/4.1+1)
    :II=INT(R/200.1+1)
    :FORI=1TOII
115 IFR-200*I>=0.0THENN=200ELSEN=200+(R-200*I)
116 FORJ=1TOJJ
    :IFC-4*J>=0.0THENL=4ELSEL=4+(C-4*J)
117 LPRINT"VAR:";
    :FORKK=0TO(L-1)
    :LPRINTTAB(14*KK+8)(KK+1)+4*(J-1);
    :NEXTKK
    :LPRINT" "
    :LPRINT"----------------------------------------------------------------"
    :FORM=1TON
    :LPRINT"O";M+200*(I-1);":";
    :FORK=1TOL
    :A=A(M+200*(I-1),K+4*(J-1))
118 LPRINTTAB(14*(K-1)+8)A;
    :NEXTK
    :LPRINT
    :NEXTM
    :LPRINT" "
    :LPRINT" "
    :LPRINT" "
    :NEXTJ,I
    :GOTO66
119 CLS
    :PRINT"YOU MUST ENTER THE EQUATION BY FIRST TYPING LINE#122"
    :PRINT"THEN ENTER THE EQUATION -- E.G. 122 Y=X[2  <ENTER> THEN RUN 120"
    :STOP
120 YU=1
    :GOSUB131
    :GOSUB124
121 CLS
    :PRINT@448,"ENTER BEGINNING VALUE OF X -->  ";
    :FL=-12
    :GOSUB2
    :BEGIN=VAL(IN$)
    :PRINT
    :PRINT"ENTER THE ENDING VALUE OF X -->  ";
    :GOSUB2
    :ED=VAL(IN$)
    :PRINT
    :PRINT"ENTER THE INCREMENT OF X --> ";
    :GOSUB2
    :INC=VAL(IN$)
    :I=1
    :GOSUB136
    :I=1
    :FORX=BE TO EDSTEPIN
122 Y1=0.252*X[2.239
    : Y2=0.178*X[2.333
    ; Y3=0.165*X[2.362
123 A(I,1)=X
    :A(I,2)=Y1
    :A(I,3)=Y2
    :A(I,4)=Y3
    :I=I+1
    :NEXTX
    :R=I-1
    :C=4
    :GOTO36
124 DIMZO(20),Z1$(52),Z0$(52),W0$(52),W1$(52)
    :DM=500
    :ZV=1
    :ZH=1
    :Z0$="FIGURE 1."
    :W0$="Y-AXIS"
    :W1$="X-AXIS"
    :WF$(1)="*"
    :WF$(2)="O"
    :WF$(3)="X"
    :WF$(4)="@"
    :WF$(5)="#"
    :WF$(6)="&"
    :RETURN
125 FORI=1TO500
    :NEXTI
    :RETURN
126 ZZ=INT(30-CC/2)
    :RETURN
127 I8=0
    :CLS
    :FORI=1TOC
    :GOSUB128
    :PRINT"VAR #";I;" = ";N$(I)
    :NEXT
    :INPUT"<ENTER> TO RETURN";A9
    :RETURN
128 I8=I8+1
    :IFI8<=10THEN129ELSEINPUT"<ENTER> FOR CONT.";A9
    :I8=1
129 RETURN
130 DIMA(R,C),T(C)
    :RETURN
131 DIMA(200,7),T(7)
    :RETURN
132 RUN
133 IFYU<>1THEN135
134 CLS
    :INPUT"<ENTER> NAME FOR DATA SET";F$
135 RETURN
136 PRINT
    :PRINT"COMPUTING VALUES"
    :RETURN
4000 A$=INKEY$
    :IFA$=""GOTO4000
```

```
LPRINT"0";M+200*(I-1);":";
FORK=1TOL
A=A(M+200*(I-1),K+4*(J-1))
PRINTTAB(14*(K-1)+3)A;
NEXTK
LPRINT
NEXTM
LPRINT" "
LPRINT" "
LPRINT" "
NEXTJ,I
GOTO66
LS
PRINT"YOU MUST ENTER THE EQUATION BY FIRST TYPING LINE#122"
PRINT"THEN ENTER THE EQUATION -- E.G. 122 Y=X[2  <ENTER> THEN RUN 120"
STOP
U=1
GOSUB131
GOSUB124
LS
PRINT@448,"ENTER BEGINNING VALUE OF X -->  ";
FL=-12
GOSUB2
BEGIN=VAL(IN$)
PRINT
PRINT"ENTER THE ENDING VALUE OF X -->  ";
GOSUB2
ED=VAL(IN$)
PRINT
PRINT"ENTER THE INCREMENT OF X --> ";
GOSUB2
INC=VAL(IN$)
I=1
GOSUB136
I=1
FORX=BE TO EDSTEPIN
1=0.252*X[2.239
 Y2=0.178*X[2.333
```

```
    ; Y3=0.165*X[2.362
123 A(I,1)=X
    :A(I,2)=Y1
    :A(I,3)=Y2
    :A(I,4)=Y3
    :I=I+1
    :NEXTX
    :R=I-1
    :C=4
    :GOTO36
124 DIMZ0(20),Z1$(52),Z0$(52),W0$(52),W1$(52)
    :DM=500
    :ZV=1
    :ZH=1
    :Z0$="FIGURE 1."
    :W0$="Y-AXIS"
    :W1$="X-AXIS"
    :WF$(1)="*"
    :WF$(2)="O"
    :WF$(3)="X"
    :WF$(4)="@"
    :WF$(5)="#"
    :WF$(6)="&"
    :RETURN
125 FORI=1TO500
    :NEXTI
    :RETURN
126 ZZ=INT(30-CC/2)
    :RETURN
127 I8=0
    :CLS
    :FORI=1TOC
    :GOSUB128
    :PRINT"VAR #";I;" = ";N$(I)
    :NEXT
    :INPUT"<ENTER> TO RETURN";A9
    :RETURN
128 I8=I8+1
    :IFI8<=10THEN129ELSEINPUT"<ENTER> FOR CONT.";A9
    :I8=1
129 RETURN
130 DIMA(R,C),T(C)
    :RETURN
131 DIMA(200,7),T(7)
    :RETURN
132 RUN
133 IFTU<>1THEN135
134 CLS
    :INPUT"<ENTER> NAME FOR DATA SET";F$
135 RETURN
136 PRINT
    :PRINT"COMPUTING VALUES"
    :RETURN
4000 A$=INKEY$
    :IFA$=""GOTO4000
```

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Rauscher, Harald M.

The microcomputer scientific software series 2: general linear model—regression. Gen. Tech. Rep. NC-85. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1983. 52 p.

The general linear model regression (GLMR) program provides the micro-computer user with a sophisticated regression analysis capability. The output provides a regression ANOVA table, estimators of the regression model coefficients, their confidence intervals, confidence intervals around the predicted Y-values, residuals for plotting, a check for multicollinearity, a check for autocorrelation, and the scaled regression coefficients. A plotting routine is part of the regression program to facilitate quick plotting of residuals.

KEY WORDS: Regression, microcomputer, BASIC, statistics.

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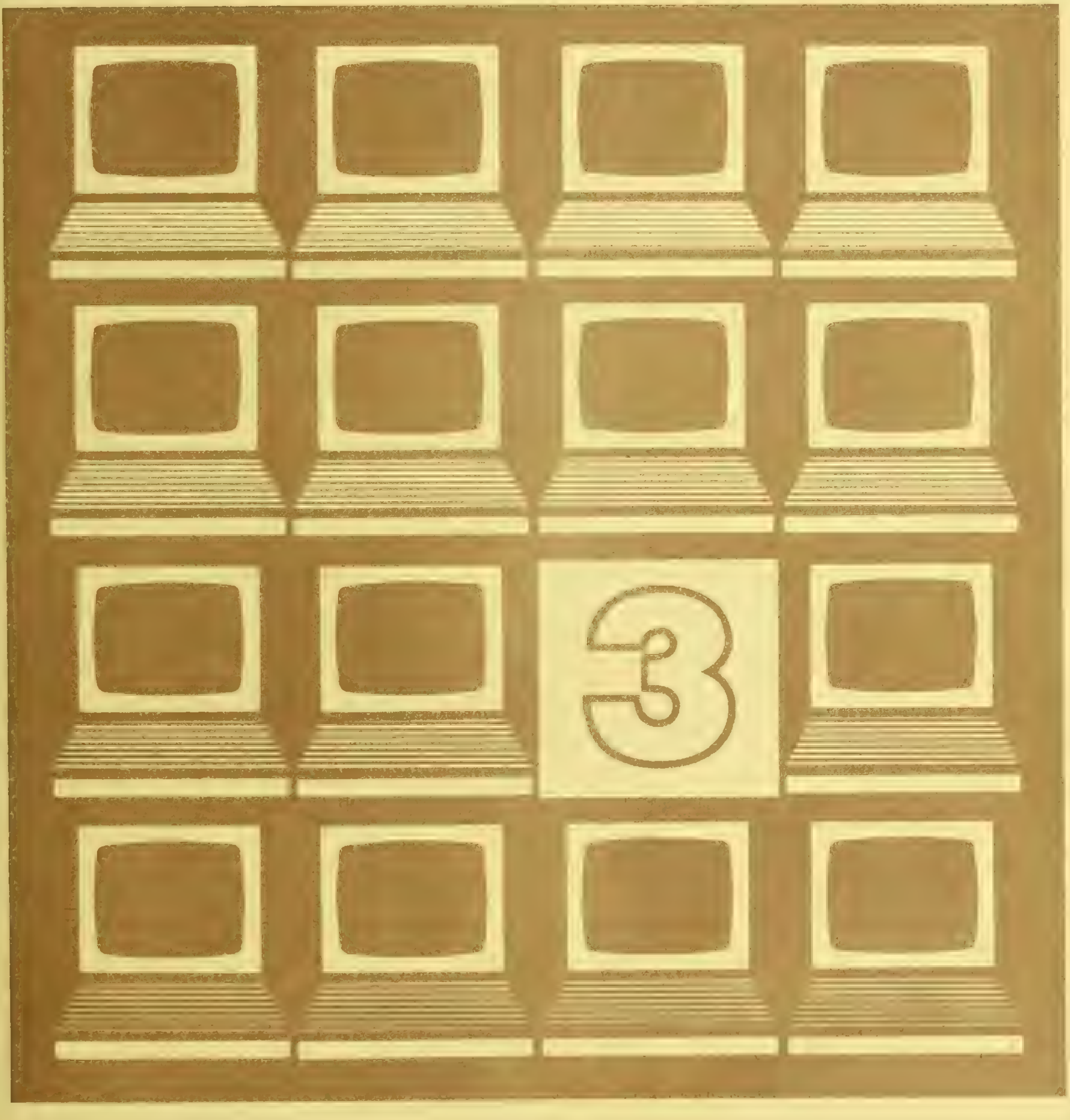
The Microcomputer Scientific Software Series 3

General Linear Model - Analysis of Variance

Harold M. Rauscher



North Central Forest Experiment Station
Forest Service—U.S. Department of Agriculture
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HE MICROCOMPUTER SCIENTIFIC SOFTWARE SERIES 3: GENERAL LINEAR MODEL—ANALYSIS OF VARIANCE

Harald M. Rauscher, *Research Forester,*
Grand Rapids, Minnesota

GENERAL INFORMATION

Identification

me: General Linear Model–ANOVA (GLMA)
ation: North Central Forest Exp. Station
1831 Highway 169 East
Grand Rapids, MN 55744
nguage: Microsoft BASIC
nputer: Radio Shack TRS-80 Microcomputer[1]

Summary

Program GLMA performs an analysis of variance
NOVA). No a-priori restrictions are imposed on the
es of experimental designs that can be analyzed.
balanced as well as balanced designs may be an-
zed and the linear model may contain nested or
ss classified factors. The user is required to set
estimable functions that lead to testable hy-
heses. An example illustrates how to obtain the
per estimable functions to compute the most fre-
ently needed sums of squares for hypothesis test-

The GLMA program displays the overall model
OVA table, the degrees of freedom, sums of squares,
l mean square for each hypothesis to be tested.
e user must select the appropriate error mean
are for each F-test, compute the F statistic, and
k up its significance level in a table of F-values.

The current version of GLMA does not perform
ariance analysis, compute variance components,
provide postiori tests on the hypotheses, nor estimate the expected values of the model parameters or their confidence intervals.

Objectives

The GLMA program and user's guide will:

(a) Provide users of small computers with a general purpose analysis of variance program, and

(b) Document the program to allow user implementation of extensions.

Intended Readership

Self-sufficiency in the area of computer data analysis is becoming increasingly more important, desirable, and financially attractive. As used above, self-sufficiency in data analysis is defined as (1) immediate, desk top access to data analytical tools, (2) cost of computer use not a function of time on the system, and (3) the power to add to, delete from, and alter the data analysis software. This is one of a series of BASIC lanquage programs designed to help interested users achieve data analysis self-sufficiency. The most important non-equipment related requirements to achieve data analytical self-sufficiency is the ability of the user to program. Those who choose not to be programmers should either have access to a programmer or depend upon packaged data analysis systems to meet their needs.

All users of BASIC programs should find this software of value either directly or as a source of computer algorithms. Users of small computers with Microsoft (tm) BASIC will be able to implement GLMA with a minimum of effort and programming knowledge. Users of small computers with other BASIC language implementations will need to reprogram

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Mention of trade names does not constitute en-
rsement of the products by the USDA Forest Service

certain basic statements. Frederick *et al.* (1979) have prepared an excellent guide for translating programs between dialects of BASIC.

All users should be familiar with the assumptions behind analysis of variance, how to construct a design matrix based on a linear model, and how to select the appropriate error mean square for each F-test.

The numerical methods are presented to allow the reader to judge their suitability.

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Quick Reference Guide

Input requirements

The user must formulate the statistical model be tested and label each element of the model as random or a fixed effect element. GLMA requir that an m by 1 matrix containing the observatio on the dependent variable (Y) be defined and locat on disk. The design matrix (X) of dimensions m n must also be created by the user and saved on di before accessing the analysis of variance progra The m stands for the number of observations a the n stands for the number of elements (colum in the design matrix.

GLMA Output

(a) ANOVA table,

(b) type I sum of squares for each hypothesis,

(c) mean square and degrees of freedom for ea hypothesis tested.

APPLICATION

Introduction

This section of the guide shows you how to u GLMA. Each option in the system relevant to ana ysis of variance is presented, discussed, and illu trated by example.

After the model has been specified, you must s up the design matrix (X). The data from a two-wa unbalanced ANOVA experiment with interacti terms (Searle 1971, p. 289) is presented in table and will be used as an example. The linear mod is:

$Y_{ijk} = mu + (alpha)_i + (beta)_j + (gamma)_{ij} + e$

where: i varies from 1 to 3
j varies from 1 to 4
k varies from 0 to 4

With balanced data, every one of the ij cells wou have a constant, k, number of observations. In t unbalanced case k varies.

To begin, initiate the operating system and act vate the BASIC interpreter of your computer syste Next, run program "GLM1/BAS". The menu of choic displayed in figure 1 will appear on the screen. O tion number 1 will redisplay the menu, number ble 1.—*Example data for a two-way, unbalanced ANOVA with interactions terms (Searle 1971, p. 289)*

$$
\begin{bmatrix}8\\13\\9\\12\\7\\11\\6\\12\\12\\14\\9\\7\\14\\16\\10\\14\\11\\13\end{bmatrix}
=
\begin{bmatrix}y_{111}\\y_{112}\\y_{113}\\y_{131}\\y_{141}\\y_{142}\\y_{211}\\y_{212}\\y_{221}\\y_{222}\\y_{321}\\y_{322}\\y_{331}\\y_{332}\\y_{341}\\y_{342}\\y_{343}\\y_{344}\end{bmatrix}
=
\begin{array}{c|ccc|cccc|cccccccc}
\mu & \alpha_1 & \alpha_2 & \alpha_3 & \beta_1 & \beta_2 & \beta_3 & \beta_4 & \gamma_{11} & \gamma_{13} & \gamma_{14} & \gamma_{21} & \gamma_{22} & \gamma_{32} & \gamma_{33} & \gamma_{34} \\
\hline
1 & 1 & \cdot & \cdot & 1 & \cdot & \cdot & \cdot & 1 & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\
1 & 1 & \cdot & \cdot & 1 & \cdot & \cdot & \cdot & 1 & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\
1 & 1 & \cdot & \cdot & 1 & \cdot & \cdot & \cdot & 1 & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\
1 & 1 & \cdot & \cdot & \cdot & \cdot & 1 & \cdot & \cdot & 1 & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\
1 & 1 & \cdot & \cdot & \cdot & \cdot & \cdot & 1 & \cdot & \cdot & 1 & \cdot & \cdot & \cdot & \cdot & \cdot \\
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1 & \cdot & \cdot & 1 & \cdot & \cdot & \cdot & 1 & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & 1 \\
1 & \cdot & \cdot & 1 & \cdot & \cdot & \cdot & 1 & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & 1 \\
1 & \cdot & \cdot & 1 & \cdot & \cdot & \cdot & 1 & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & 1
\end{array}
\begin{bmatrix}\mu\\ \hdashline \alpha_1\\ \alpha_2\\ \alpha_3\\ \hdashline \beta_1\\ \beta_2\\ \beta_3\\ \beta_4\\ \hdashline \gamma_{11}\\ \gamma_{13}\\ \gamma_{14}\\ \gamma_{21}\\ \gamma_{22}\\ \gamma_{32}\\ \gamma_{33}\\ \gamma_{34}\end{bmatrix}
+
\begin{bmatrix}\varepsilon_{111}\\ \varepsilon_{112}\\ \varepsilon_{113}\\ \varepsilon_{131}\\ \varepsilon_{141}\\ \varepsilon_{142}\\ \varepsilon_{211}\\ \varepsilon_{212}\\ \varepsilon_{221}\\ \varepsilon_{222}\\ \varepsilon_{321}\\ \varepsilon_{322}\\ \varepsilon_{331}\\ \varepsilon_{332}\\ \varepsilon_{341}\\ \varepsilon_{342}\\ \varepsilon_{343}\\ \varepsilon_{344}\end{bmatrix}
$$

$$Y = X\,B + E$$

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MENU FOR: GENERAL LINEAR MODEL–ANOVA

RETURN TO MAIN MENU
2. GOTO BASIC
READ A MATRIX FROM DISK
4. WRITE A MATRIX TO DISK
ENTER A MATRIX MANUALLY
6. DISPLAY MATRIX ON VIDEO
PRINT MATRIX
8. GENERAL LINEAR MODEL
LECT ONE OF THE ABOVE —

gure 1.—*Control Menu for Program GLMA.*

will exit the program and return control to the BASIC interpreter, number 3 is used to read a data matrix from the disk, and number 7 allows printing of the data matrix.

If matrix Y is not already stored on disk, select number 5 to enter it from the keyboard. When you are asked for the number of rows and columns (m,n) in the matrix, enter <18,1>. Then, when you are asked to give the first column a name, enter <Y>. Finally, you are asked to enter the data elements. For 1,1 enter <8>, for 2,1 enter <13>, and so on (see data in table 1).

After the 18th element has been entered, you are returned to the menu of options. Select number 6 to display your matrix. Notice that only 13 of the 18 rows of Y are displayed at one time. Pressing the down arrow on the keyboard displays the next "page" of data. Pressing the up arrow returns the first page to the screen. When a matrix has more than four columns, only four columns will be displayed on any given "page". The left and right arrows move the "page" across the desired sections of the matrix. To return to the menu, press the <CLEAR> button.

Selecting option number 4 allows you to save Y on disk. When queried for the file name under which the matrix will be saved, avoid labeling it "Y" because the program uses the disk file names Y, X, XPX, and XPXI to store intermediate results. Next, you are asked to specify the disk where you want to store the matrix. Using the TRS-80, always choose a drive other than drive O. This practice ensures sufficient disk storage capacity for the intermediate matrices.

The design matrix (X) (table 1) can be entered onto disk the same way. Notice, however, the sparcity of 1's in a field of 0's. The X matrix can be created easily by using the numerical information manipulation system (NIMS) (Rauscher 1983a). NIMS was designed to help you manipulate data matrices. It can be used to create an 18 by 16 matrix of zeroes in one command. The alter subroutine in NIMS can then be used to create full or partial columns of 1's.

Once Y and X are stored on disk 1, select number 9 (fig. 1). You are asked to enter the filename of the Y and X matrices. Remember that these filenames are not necessarily "Y" and "X". These are read into the active memory and the program executes. After a variable waiting period, you are asked to enter the number of significant figures in the raw data. Because of errors in the original data and errors due to computer floating point arithmetic, it is not possible to distinguish small singular values from zero singular values. A tolerance value, based on the number of significant figures in the data and on machine precision, is used to identify the effective number of non-zero singular values.

Before the display of the ANOVA table you are asked if you want the grand mean displayed. Including the grand mean causes the ANOVA to dislay the sum of squares that has been accounted for by the mean. This sum of squares is not presented in the "usual" ANOVA table.

The ANOVA display (fig. 2) presents the sum of squares associated with the overall model, the error sum of squares, and the total sum of squares for the example. Additionally, pertinent summaries concerning the dependent variable Y are given. Depressing the <ENTER> key returns you to the query about including the mean or not. Fianlly, the B and the (X'X) ^{1} matrices are saved onto the disk and you are given the chance to review and/or print the (X'X) matrix. The second program, GLM2/BAS, then automatically loads and executes.

Program GLM2 reads the X matrix from disk and computes the X'X matrix. After transferring the X'X matrix onto disk, you are given the opportunity to display it on the screen, print it, or continue processing. Next, you are asked if you want the estimable functions that lead to Type I sum of squares. If the answer is yes, the computations proceed and the result is automatically displayed on the video screen (table 2). Enter <CLEAR> and you can choose to print the estimable functions.

The third program o the series, GLM3/BAS, is read into memory, the generalized inverse of X'X and the X'X matrices are read from disk, and the H matrix is computed. After the B vector is read from disk, you are asked to create the test matrix K by supplying the estimable functions. You may enter estimable functions of your own design or you may enter the previously computed estimable functions that will lead to Type I sums of squares. The matrix of estimable functions is a square matrix in which the name of row i corresponds to the name of column i (table 2). For instance, both columns 2-4 and rows 2-4 correspond to the alpha effects in the model. It is best to draw lines across the rows to separate the first row, representing mu, population mean, from the remaining rows. Next, draw a line separating the alpha effect, rows 2, 3, and 4, from the remainder. Draw a line after row 8 to separate out the beta effect. Rows 9 to 16 correspond to the interaction effect, gamma. To create the test matrix, which will compute the sum of squares for the alpha effect, simply enter every non-zero row from the estimable function block that designatesd the alpha effect. In this case, there are two non-zero rows in the alpha effect block, i.e. row 2 and 3. Thus the K matrix will have two rows giving the alpha effect 2 degrees of freedom. Similarly, the beta effect has three non-zero

```
     REGRESSION ANALYSIS OF
         VARIANCE TABLE

Source  SS    SS       MS       F    Probability
Model    7  81.9988 11.7141 2.0918     0.1399
Error   10    56       5.6
Total   17  137.999
Mean of Response Variable Y = 11
Std. Dev. of Error = 2.36643 C.V. of Y = 21.5
Multiple Correlation Coefficient (R**2) = .549199
```

Figure 2.—*ANOVA display for example problem.*

ble 2.—*Estimable functions that lead to Type I sum of squares for the example problem*

	μ	α_1	α_2	α_3	β_1	β_2	β_3	β_4	γ_{11}	γ_{13}	γ_{14}	γ_{21}	γ_{22}	γ_{32}	γ_{33}	γ_{34}
μ	1	.33	.22	.44	.28	.22	.17	.33	.17	.06	.11	.11	.11	.11	.11	.22
α_1	0	1	-.33	-.67	.33	-.33	0	0	.5	.17	.33	-.17	-.17	-.17	-.17	-.33
α_2	0	0	1	-1	.5	.25	-.25	-.5	0	0	0	.5	.5	-.25	-.25	-.5
α_3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
β_1	0	0	0	0	1	-.4	-.2	-.4	.6	-.2	-.4	.4	-.4	0	0	0
β_2	0	0	0	0	0	1	-.33	-.67	.29	-.1	-.19	-.29	.29	.71	-.24	-.48
β_3	0	0	0	0	0	0	1	-1	0	.33	.33	0	0	0	.67	-.67
β_4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	1	-.33	-.67	-1	1	-1	.33	.67
13	0	0	0	0	0	0	0	0	0	1	-1	0	0	0	-1	1
14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

ows, i.e. 5, 6, and 7. These rows are entered as es-mable functions, one at a time, thus creating a K atrix with three rows and 3 degrees of freedom for e beta effect sum of squares. The interaction effect, amma, has only two non-zero rows which become e estimable functions in K, yielding 2 degrees of eedom for the interaction sum of squares. The sum f the degrees of freedom of the alpha, beta, and amma effects must equal to the overall model de-rees of freedom.

When each set of estimable functions has been ntered, you are asked whether the M vector (right and side of the hypotheses) is zero. Usually it is. n the example, assume that M is a zero vector. The rogram executes the estimability check. If a K ma-rix is found that is not estimable, you are advised nd allowed to build another K matrix. If you used e computed estimable functions, then you will pass e error check.

The program computes and displays the hypoth-sis sum of squares, the mean square, and the as-ociated degrees of freedom for each set of estimable functions (table 3). The F-statistic, used for testing a null hypothesis, is computed by dividing the mean square for the null hypothesis by an appropriate error mean square. The selection of the denominator mean square depends on the expected mean squares (ems) for each effect in the model. GLMA does not compute ems. The user must first decide whether the model is a fixed effects, random effects, or mixed effects model an then calculate the appropriate ems. Given the appropriate ems and the numerator mean squares calculated by this program, the user can readily compute the appropriate F-statistic to test hypotheses.

Table 3.—*Analysis of variance results for the example two-way classification with interaciton (see Table 1)*

Source	Clf.	Sum of squares	Mean square
Alpha	2	10.50	5.25
beta	3	36.79	12.26
gamma	2	34.71	17.36

PROCEDURES AND REQUIREMENTS

System Characteristics

Program GLMA is written in BASIC for the TRS-80 microcomputer. The computer should have a minimum of 48K of user definable random access memory (RAM), two disk drives, and a lineprinter. Experience with the TRS-80 has shown that it is best to mount the operating disk with the GLMA programs on disk drive 0 (see TRS-80 owners manual) and use disk drive 1 to store and retrieve the data matrices. Because highly compatible versions of BASIC are available for most microcomputer systems, I believe that this program can easily be converted to execute on most computer systems that execute some dialect of the BASIC language.

Performance

Available memory and speed of computation are the primary limits to performing ANOVA using GLMA. The dimensions of the design matrix (X) must be set to the number of observations (rows) in the analysis and the number of effects (columns) in the model to be analyzed. These dimensions will vary between problems. Line number 40000 in each of the three subprograms that make up GLMA contains the BASIC dimension statement that defines the size of the response and design matrices. In general the program can process an X matrix with 100 rows and 25 columns. Using fewer rows increases the maximum number of columns possible and vice versa.

Processing speed varies with the dimensions of the X matrix. The following examples may be used as an index of processing speed: X(12,8) about 4.5 minutes; X(18,16) about 17 minutes; X(37,5) about 7 minutes; and X(24,20) about 37 minutes. Processing times were measured from the start of the program until the overall model ANOVA table was displayed. These times could be improved by a factor of 10 by compiling GLMA using the BASIC compiler available for the TRS-80.

Data Compatibility

Program GLMA uses the data interchange standard (DIS) proposed by Buhyoff *et al.* (1980). This standard is described in detail by Rauscher and Buhyoff (1982). Using a common DIS decreases program development time and isolates system dependencies into small, explicit subroutines. Using a common DIS enforces a "standard" input/output structure on data transferred between disks. This "standard" structure unites otherwise independent data analysis programs. The input matrices required by this program may be created by GLMA or by the numerical information manipulation system (NIMS) reported by Rauscher (1983a). These two programs and many others (Buhyoff *et al.* 1980) are compatible because they both use the DIS. Because the X matrix contains mostly 0's, it is efficient to allow the computer to create a design matrix with all zeroes. The alteration routine in NIMS may then be used to change the appropriate zeroes into 1's.

Analysis of Variance—Theory

Program GLMA is based upon the theory of general linear models presented by Searle (1971). The problem in analysis of variance (ANOVA), as in regression, is to find a solution to:

$$Y = X B + E \quad (2)$$

where:

Y = the m by 1 matrix of observations on the dependent variable
X = the m by n design matrix
B = the n vector of parameters
E = Y−XB = an m vector of random errors

Every element in E is assumed to have variance (sigma)^{2}and zero covariance with every other element (Searle 1971). The regression analysis problem is defined when X is of full rank, i.e. $r(X)<n$.

In ANOVA, the X matrix is called the design matrix because it carries the code for the design of the analysis. It contains only 0's and 1's derived directly from the hypothesized design model under investigation. The solution to (2) is:

$$\hat{B} = (X'X)^{-1} X' Y \quad (3)$$

where:

$\hat{B}$ = the n vector of estimates of parameters
X' = transpose of X
$(X'X)^{-1}$ = inverse of X'X.

However, X'X has no unique inverse because it is not full ranked. X'X does have many generalized inverses, any one of which can be used to solve the problem. Equation (3) may be restated as:

$$\hat{B} = GY \quad (4)$$

where:

G = any generalized inverse of X.

The singular value decomposition algorithm of Golub and Reinsch (1970) is used to solve (4). A singular value decomposition of an m by n real matrix X, is any factorization of the form:

$X = U S V'$ (5)

here:

S = an m by n diagonal matrix of singular values
if $S_{ii} < q$ then $S_{ii} = 0$
S_{ii} = ith singular value
q = a tolerance value based on the precision of the data in the X matrix
U = an m by m orthogonal matrix
V = an n by n orthogonal matrix.

$G = V S^+ U'$ where: S^+ = as above except $S^+_{ii} =$ S_{ii} (6)

$\hat{B} = (X'X)^{-1} X' Y = V S^+ U' Y$ (Forsythe *et al.* 77) (7)

$'X)^{-1} = V (S^+)^2 V'$ (Nash 1979) (8)

sing these results as the basis, the sums of squares n be computed as outlined in Searle (1971):

$E'E$ = error sum of squares = SSE (9)

$\text{sigma}^2 = \text{SSE}/(m-r(X))$ (10)

here:

sigma^2 = Residual error estimate of variance
m = number of observations
$r(X)$ = rank of X

$\text{SST} = Y'Y$ = total sum of squares (11)

$\text{SSR} = \text{SST} - \text{SSE}$ = sum of squares due to gression (12)

$\text{SSM} = m * Y^2$ = correction term for the mean (13)

here:

Y = mean of Y

$\text{SSRm} = \text{SSR} - \text{SSM}$ = regression sum of squares rrected for the mean (14)

$\text{SSTm} = \text{SST} - \text{SSM}$ = corrected sum of squares f dependent variable Y (15)

$R^{**}2 = \text{SSRm}/\text{SSTm}$ = coefficient of etermination. (16)

To test hypotheses, we must assume that the erors are normally, independently, and identically disributed. If we can make these assumptions, F(R) ig. 3A) tests the hypothesis that $XB=0$. If F(R) is ignificant, we conclude that the model accounts for significant portion of the variation in the y-varible. F(M) (fig. 3B) tests the hypothesis that $E(Y)=0$, e. the expected value of the mean of the Y obserations is zero. F(M) is given by GLMA when the NOVA display with the mean is requested. F(R) can be computed from the ANOVA display with the mean by first summing up the sums of squares due to the mean and the model after the mean has been accounted for and then dividing by the sum of the model degrees of freedom and the error mean square. F(Rm) (fig. 3C) provides a test of the model $E(Y) = XB$ over and above the mean. F(Rm) is displayed in the ANOVA without the mean displayed. When F(Rm) is significant, we conclude the model satisfactorily accounts for variation over and above the mean. If all three F-statistics are significant, then:

"F(R), F(M), and F(Rm) indicate, respectively, that the model accounts for a significant portion of the variation in y, that the mean is unlikely to be zero, and that the model needs in it something more than the mean to explain variation in y" (Searle 1971, p. 180).

Estimable Functions

Once the sum of squares for the overall model has been computed, we generally wish to decompose this value into the various sum of squares for each main effect and interaction term in the model. This amounts to partitioning the sum of squares of regression (SSRm) after fitting the mean (fig. 3C). The major statistical analysis packages such as SAS (Helwig and Council 1979) partition the model sum of squares automatically by assuming the investigator desires to test "standard" hypotheses. An option is available for the user who needs to test additional hypotheses. GLMA is not capable of automatically partitioning the model sum of squares.

The user must create the matrix of estimable functions (K) for testing of hypotheses:

HO: $K' B = M$ (17)

where:

HO = null hypothesis under test
K = matrix of estimable functions
M = right hand side of the hypothesis (often equal to the zero vector) The B vector is supplied by the program and calculated as in (7).

The GLMA program supplies the user with the X'X matrix, the $X'X^{-1}$ matrix, and the matrix of estimable functions that lead to the computation of Type I sums of squares. Type I sums of squares are discussed by Helwig and Council (1979, p. 254) and by Goodnight (1978, p. 6). This program uses the Forward Doolittle method (Steel and Torrie 1960) on the X'X matrix to compute the estimable functions that lead directly to the Type I sum of squares.

(MODEL: $Y_{ijk} = \mu + \alpha_i + \beta_j + \gamma_{ij} + \varepsilon_{ijk}$)

	Source	D.F.	SS	MS	F-Statistic
	Model	8	2260 (SSR)	282.5	50.4 = F(R)
(A)	Error	10	56 (SSE)	5.6	
	Total	18	2316 (SST)		

	Source	D.F.	SS	MS	F-Statistic
	Mean:	1	2178 (SSM)	2178	388.9 = F(M)
(B)	Model: $\alpha, \beta, \gamma \mid \mu$	7	82 (SSRm)	11.71	2.1 = F(Rm)
	Error	10	56 (SSE)	5.6	
	Total	18	2316 (SST)		

	Source	D.F.	SS	MS	F-Statistic
	Model: $\alpha, \beta, \gamma \mid \mu$	7	82 (SSRm)	11.71	2.1 = F(Rm)
(C)	Error	10	56 (SSE)	5.6	
	Total	17	138 (SSTm)		

Note: $\alpha, \beta, \gamma \mid \mu$ = model effects after the effect of the mean has been removed.

Figure 3.—*Example of ANOVA tables from program GLMA.*

A testable hypothesis is one that can be expressed in terms of estimable functions. To ensure that the user specified estimable functions are testable, the following identity is verified in the GLMA program:

$$K' = K' H \qquad (18)$$

where:

$H = G X' X$

The sum of squares necessary to test the hypothesis HO: $K'B = M$ is supplied by the program and computed as:

$SS(HO) = (K'B-M)' (K'GK)^{-1} (K'B-M)$ (1
= sum of squares of hypothesis

$s = r(K')$ = number of rows in K' (2

where:

K' is by definition of full rank

$MS(HO) = SS(HO)/s$ = mean square hypothesis (2

Program Code Documentation

roduction

The programs are coded in the Microsoft (TM)
SIC language for direct use with the Radio Shack
M) Level II BASIC interpreter. Unlike many other
guages, some versions of BASIC allow concaten-
on of several logical statements in one physical
e. Microsoft BASIC uses the colon, ":", as the log-
l statement delimiter. Because each physical line
ts 5 bytes of memory and each unnecessary space,
yte, small computer BASIC programs are written
compressed code and appear impossible to deci-
er, especially for those who normally program in
RTRAN. To make matters worse, internal pro-
m documentation is reduced to a minimum in
SIC because these statements use memory. Given
se memory constraints and the ability to refer
ambiguously to any physical line in the program,
elieve that adequate documentation of BASIC pro-
ms should be accomplished external to the code.
e code is presented in the appendix with only one
ical statement per line. Each logical statement
y begin either with a linenumber or a colon. One
ysical line consists of a linenumbered statement
l all the colon statements until the next linen-
bered statement. Each section of code is explained
he following presentation by reference to physical
enumbers.

GLMA is composed of three separate programs:
MI/BAS, GLM2/BAS, and GLM3/BAS.

ogram GLM1/BAS

Program GLMI/BAS is almost identical to pro-
am GLR/BAS, fully documented by Rauscher (1983b). Lines 2382–2395 in GLR have been deleted and line 2415 added to GLM. Line 2415 allows display or printing of the generalized inverse matrix (X'X).

Program GLM2/BAS

Lines 13-690 comprise the common SEED program documented by Rauscher (1983a). In line 1045, the dimensioning routine is accessed in line 40000 and in line 1070, the X matrix is read from the disk. Lines 1080-1110 compute the X'X matrix, transfer it to the input-output matrix, A(.,.), save it to disk, and give the opportunity to display it on the video screen and/or print it on a lineprinter. In lines 1115-1180, the matrix of estimable functions for use in calculating type I sum of squares is computed. The procedure used is the Forward Doolittle method (Goodnight 1978, p. 12-14). The matrix of estimable functions is displayed, the user is asked whether it is to be printed, and the next program is called (line 1190).

Program GLM3/BAS

Lines 13-920 are the SEED program subroutines that accept input from the keyboard, read data from disk, and write data to disk. Lines 1050-1100 read in the matrices, $(X'X)^{-1}$, X'X, and B, and compute the H matrix. Lines 1110-1180 handle the input from the keyboard of the estimable functions, matrix K and matrix M. Subroutine 6000-6100 tests for estimability. Lines 1205-1260 calculate the pieces of equation (17) using the matrix inversion routine (lines 8500-9450) documented by Rauscher (1983a). The degrees of freedom, sum of squares, and mean square appropriate to the estimable functions used is displayed by line 1280. The user is then routed to another hypothesis test or prompted to run another problem.

APPENDIX I. Source code listing for program GLMI/BAS

```
10 CLEAR 500
    :TX=-1
    :GOTO700
    :'GLM1/BAS VERSION 09/01/81
13 '***********************************************
14 'ANSWER INPUT ROUTINE
15 P=( 256*PEEK( 16417 )+PEEK( 16416 ))-15359
    :IF ABS(FL )=1THEN16ELSE24
16 IN$=""
    :PRINT@P,CHR$( 136 );
    :LX=1
17 IN$=INKEY$
    :IFIN$=""THEN22
18 IFFL=-1 AND ASC( IN$ )>47 AND ASC( IN$ )<58 THEN 21
19 IF FL=1 AND ASC( IN$ )>64 AND ASC( IN$ )<91 THEN 21
20 GOTO 22
21 PRINT@P,IN$
    :RETURN
22 LX=LX+1
    :IFL<16THEN17
23 PRINT@P," ";
    :FORLX=1TO25
    :NEXT
    :GOTO16
24 PRINT@P, CHR$( 136 );
    :IN$=""
    :LX=ABS( FL )
    :GOSUB34
25 A$=INKEY$
    :IFA$=""THEN25
26 IFA$=CHR$( 13 )THENPRINTCHR$( 15 );
    :RETURN
27 IF A$=CHR$( 8 )THENIFIN$<>""THENPRINTA$;
    :PRINTCHR$( 136 );CHR$( 24 );
    :IN$=LEFT$( IN$,LEN( IN$ )-1 )
    :LX=LX+1
    :GOTO25
    :ELSEGOTO28
28 IF A$=CHR$( 24 )THENPRINTCHR$( 29 );
    :GOTO24
29 IF FL>0 AND ASC( A$ )>31 AND ASC( A$ )<91 THEN 32
30 IF FL<0 AND ASC( A$ )>=45 AND ASC( A$ )<58 THEN 32
31 GOTO 25
32 IF LX=0 THEN 25
33 PRINT A$;
    :IN$=IN$+A$
    :LX=LX-1
    :GOTO25
34 FOR IX=1TOLX-1
    :PRINT CHR$( 136 );
    :NEXT
    :FORJX=1TOLX
    :PRINT CHR$( 24 );
    :NEXT
    :RETURN
50 '**********************************
52 'CHANGE VARIABLE NAMES
54 '///////////////
56 CLS
    :PRINT@448,"WHICH COLUMN'S NAME WILL BE CHANGED? --> ";
```

```
  :FL=-2
  :GOSUB15
  :XJ=VAL(IN$)
  :PRINT
  :PRINT"PLEASE ENTER NEW NAME --> ";
  :FL=8
  :GOSUB15
  :N$(XJ)=IN$
  :RETURN
10 '****************************************
10 'READ SEQUENTIAL DATA SET FROM DISK
10 '//////////////////////
15 CLS
10 PRINT@448,"ENTER FILENAME OF DESIRED DATA SET --> ";
  :INPUT F$
15 FF$=F$+"N"
  :L$=F$+"L"
  :F$=F$+"M"
10 OPEN "I",1,FF$
  :INPUT#1,R,C
  :CLOSE1
  :'GET R,C VALUES
15 OPEN "I",1,L$
  :FORK=1TOC
  :INPUT#1,N$(K)
  :NEXTK
16 CLOSE
10 OPEN "I",1,F$
  :
50 FORI=1TOR
  :FORJ=1TOC
  :INPUT#1,A(I,J)
  :NEXTJ,I
70 CLOSE 1
30 RETURN
70 '********************************************
00 ' WRITE A SEQUENTIAL MATRIX TO DISK
.0 '//////////////////////
20 CLS
  :PRINT@448,"ENTER FILENAME OF NEW DATA SET --> ";
  :INPUT F$
  :PRINT
  :PRINT"ENTER DISK DRIVE # WHERE DATA SHOULD BE SAVED --> ";
  :INPUT DD$
22 FF$=F$+"N:"+DD$
  :L$=F$+"L:"+DD$
  :F$=F$+"M:"+DD$
25 FOR JQ=1TOC
  :IF LEN(N$(JQ))=0 THEN N$(JQ)=STR$(JQ)
26 NEXT
30 OPEN "O",1,FF$
  :PRINT#1,R;C;
  :CLOSE1
40 OPEN "O",1,F$
  :
50 FORI=1TOR
  :FORJ=1TOC
  :PRINT#1,A(I,J);
  :NEXTJ,I
50 CLOSE 1
```

```
265 OPEN"O",1,L$
    :FORI=1TOC
    :PRINT#1,N$(I);",";
    :NEXT
    :CLOSE
270 RETURN
290 REM ****************************************************
295 REM                  SUBROUTINE INPUT
300 '1.  THIS SUB READS FROM THE KEYBOARD
305 '2.  MATRIX A IS LOADED AND CAN BE SAVED ON DISK
325 '6.  14-APR-79
335 REM ****************************************************
340 CLS
345 INPUT "PLEASE ENTER: NO. ROWS AND COLS (R,C).--> ";R,C
350 FL=8
    :PRINT
    :FOR J=1TOC
    :PRINT"ENTER THE NAME FOR VARIABLE ";J;" --> ";
    :GOSUB15
    :N$(J)=IN$
    :PRINT
    :NEXT
355 CLS
365 FOR I=1 TO R
370 PRINT "ROW ";I
375 FOR J=1 TO C
380 FL=-12
    :PRINT "PLEASE ENTER:  VALUE OF COLUMN ";J" --> ";
    :GOSUB 15
385 PRINT
390 A(I,J)=VAL(IN$)
395 NEXT J
400 NEXT I
430 RETURN
435 END
440 '****************************************************
445 '           SUBROUTINE VIDEO
450 '   DISPLAYS MATRIX A(R,C),13 ROWS BY 4 COLUMNS AT ONCE
455 ' USES ARROWS IN ALL DIRECTIONS TO SEE DIFFERENT PAGES
460 ' OF DATA.  "CLEAR" WILL TERMINATE DISPLAY
500 '*******************************************************
510 CLS
    :IFR=0 OR C=0 THEN RETURN ELSE JJ=INT(C/4.1+1)
    :II=INT(R/13.1+1)
515 I=1
    :J=1
525      IF R-13*I>=0.0 THEN N=13 ELSE N=13+(R-13*I)
535      IF C-4*J>=0.0 THEN L=4 ELSE L=4+(C-4*J)
540 CLS
    :PRINT"COL:";
    :FOR KK=0TO(L-1)
    :PRINT TAB(14*KK+8) N$((KK+1)+4*(J-1));
545 NEXT KK
    :PRINT
550 PRINT"--------------------------------------------------------------"
555 FOR M=1 TO N
560 PRINT "R";M+13*(I-1);":";
565 FOR K=1 TO L
570 A=A(M+13*(I-1),K+4*(J-1))
575 PRINT TAB(14*(K-1)+8) A;
```

```
80 NEXT K
   :PRINT
85 NEXT M
86 A$=INKEY$
   :IFA$=""GOTO586
87 IF  ASC( A$ )=31THEN619ELSEIFASC( A$ )=9THEN588ELSE590
88 IF J+1>JJTHENJ=1ELSEJ=J+1
89 GOTO 525
90 IF  ASC( A$ )=8THEN591ELSE593
91 IF  J-1<=0THENJ=JJ ELSE  J=J-1
92 GOTO 525
93 IF  ASC( A$ )=10THEN594ELSE596
94 IF  I+1>IITHENI=1ELSEI=I+1
95 GOTO 525
96 IF  ASC( A$ )=91THEN597ELSE599
97 IF  I-1<=0THENI=IIELSEI=I-1
98 GOTO 525
99 IF  ASC( A$ )=64 THEN 600 ELSE 601
00 GOSUB 670
   :GOTO525
01 IF  ASC( A$ )=46 THEN GOSUB 50 ELSE 618
02 GOTO 525
18 GOTO586
19 RETURN
   :END
20 '*************************************************
22 'LINEPRINTER OUTPUT ROUTINE
23 IF R=0 OR C=0 THEN RETURN
24 AN$="DATA SET NAME --> "
   :CLS
   :PRINT@448,"PRESS <ENTER> WHEN PRINTER IS READY.";
   :INPUT AN
   :T$=LEFT$(F$,LEN(F$)-1)
   :T$=AN$+T$
   :GOSUB42000
   :LPRINT TAB(ZZ);T$
   :LPRINT " "
   :LPRINT " "
630 JJ=INT(C/4.1+1)
   :II=INT(R/200.1+1)
632 FORI=1TOII
634 IFR-200*I>=0.0THENN=200ELSEN=200+(R-200*I)
636 FORJ=1TOJJ
638 IFC-4*J>=0.0THENL=4ELSE L=4+(C-4*J)
640 LPRINT"COL:";
   :FORKK=0TO(L-1)
   :LPRINT TAB(14*KK+8) N$((KK+1)+4*(J-1));
642 NEXT KK
644 LPRINT" "
646 LPRINT"------------------------------------------------------------"
648 FOR M=1TON
650 LPRINT "R";M+200*(I-1);":";
652 FOR K=1TO L
654 A=A(M+200*(I-1),K+4*(J-1))
656 LPRINT TAB(14*(K-1)+8) A;
658 NEXT K
660 LPRINT
662 NEXT M
664 LPRINT " "
   :LPRINT " "
```

```
    :LPRINT " "
666 NEXT J,I
668 RETURN
670 '**********************************
671 'SCREEN PRINT ROUTINE-  ACTIVATED BY PROGRAMMED "@" ASC(64)
672 '////////////////////
673 IF PEEK(14312)<>63 THEN RETURN
674 LPRINT STRING$(64,"+")
675 FOR N1= 15360 TO 16383 STEP 64
676 A$=" "
679 FOR Q=0TO63
680 Z=PEEK(N1+Q)
    :IFZ>0ANDZ<27THENZ=Z+64ELSEIFZ<32THENZ=32
681 IFZ>=127 AND Z<=191 THEN Z=42
682 B$=CHR$(Z)
683 A$=A$+B$
684 NEXT Q
685 IF  PEEK(14312)<>63THEN RETURN
686 LPRINT " "
    :LPRINT A$
687 NEXT N1
688 LPRINT STRING$(64,"+")
689 FORN=1TO3
    :LPRINT "  "
    :NEXT
690 RETURN
695 RUN"MAIN/BAS"
    :END
700 '**************************************************
710 'GENERALIZED I/O SUBROUTINES FOR PROGRAM STARTERS
720 '/////////////////////////
735 CLS
    :T$="NORTHERN HARDWOODS LABORATORY, USFS, MARQUETTE, MI"
    :GOSUB42000
736 T$="///////////////////////////////////////////////////////"
    :GOSUB42000
737 PRINT
738 T$="MENU FOR:  GENERAL LINEAR MODEL - ANOVA
739 GOSUB42000
    :PRINT
740 IF  TX=-1 THEN GOSUB 40000 ELSE 750
750 TX=1
    :PRINT"  1.  RETURN TO MAIN MENU          2.  GOTO BASIC
760 PRINT"  3.  READ A MATRIX FROM DISK      4.  WRITE A MATRIX TO DISK
770 PRINT"  5.  ENTER A MATRIX MANUALLY      6.  DISPLAY MATRIX ON VIDEO
780 PRINT"  7.  PRINT MATRIX                 8.  GENERAL LINEAR MODEL
900 PRINT
    :PRINT"SELECT ONE OF THE ABOVE --> ";
    :FL=-2
    :GOSUB15
    :AN=VAL(IN$)
    :IFAN<=0ORAN>16THEN740
910 ON AN GOSUB 695,43000,125,220,340,510,620,2000
920 GOTO 735
1000 '*********************************************
1010 'SINGULAR VALUE DECOMPOSITION
1020 'FORSYTHE 1977 CH.9 PP.193-235
1030 'INPUT
    : A(M,N) WHERE M>=N
1040 'OUTPUT
```

```
  : W CONTAINS N UNORDERED SINGULAR VALUES OF A
050 '          U & V CONTAIN THEMSELVES
060 '//////////////////////////////
065 MV$="TRUE"
   :MU$="TRUE"
070 IE=0
   :R1=R
   :C1=C
   :M=R
   :N=C
   :NM=R
   :FORI=1TOM
   :FORJ=1TON
   :U(I,J)=A(I,J)
   :NEXTJ,I
080 'HOUSEHOLDER REDUCTION TO BIDIAGONAL FORM
090 G=0
   :SCALE=0
   :AR=0
100 FORI=1TON
   :L=I+1
   :RV1(I)=SCALE*G
   :G=0
   :S=0
   :SCALE=0
   :IFI>MTHEN1160
110 FORK=ITOM
   :SCALE=SCALE+ABS(U(K,I))
   :NEXTK
   :IFSCALE=0THEN1160
1120 FORK=ITOM
   :U(K,I)=U(K,I)/SCALE
   :S=S+U(K,I)[2
   :NEXTK
1130 F=U(I,I)
   :SS=SGN(F)
   :G=-1*SS*ABS(SQR(S))
   :H=F*G-S
   :U(I,I)=F-G
   :IFI=NTHEN1150
1140 FORJ=LTON
    :S=0
    :FORK=ITOM
    :S=S+U(K,I)*U(K,J)
    :NEXTK
    :F=S/H
    :FORK=ITOM
    :U(K,J)=U(K,J)+F*U(K,I)
    :NEXTK
    :NEXTJ
1150 FORK=ITOM
    :U(K,I)=SCALE*U(K,I)
    :NEXTK
1160 W(I)=SCALE*G
    :G=0
    :S=0
    :SCALE=0
    :IFI>MORI=NTHEN1230
1170 FORK=LTON
    :SCALE=SCALE+ABS(U(I,K))
```

```
     :NEXTK
     :IFSCALE=0THEN1230
1180 FORK=LTON
     :U(I,K)=U(I,K)/SCALE
     :S=S+U(I,K)[2
     :NEXTK
1190 F=U(I,L)
     :SS=SGN(F)
     :G=-1*SS*ABS(SQR(S))
     :H=F*G-S
     :U(I,L)=F-G
1200 FORK=LTON
     :RV1(K)=U(I,K)/H
     :NEXTK
     :IFI=MTHEN1220
1210 FORJ=LTOM
     :S=0
     :FORK=LTON
     :S=S+U(J,K)*U(I,K)
     :NEXTK
     :FORK=LTON
     :U(J,K)=U(J,K)+S*RV1(K)
     :NEXTK
     :NEXTJ
1220 FORK=LTON
     :U(I,K)=SCALE*U(I,K)
     :NEXTK
1230 TT=ABS(W(I))+ABS(RV1(I))
     :IFTT>ARTHENAR=TT
1240 NEXTI
1250 'FORM THE V MATRIX IF MV="TRUE"
1260 IFMV$="TRUE"THEN1270ELSE1350
1270 FORII=1TON
     :I=N+1-II
     :IFI=NTHEN1320
1280 IFG=0THEN1310
1290 FORJ=LTON
     :V(J,I)=(U(I,J)/U(I,L))/G
     :NEXTJ
1300 FORJ=LTON
     :S=0
     :FORK=LTON
     :S=S+U(I,K)*V(K,J)
     :NEXTK
     :FORK=LTON
     :V(K,J)=V(K,J)+S*V(K,I)
     :NEXTK
     :NEXTJ
1310 FORJ=LTON
     :V(I,J)=0
     :V(J,I)=0
     :NEXTJ
1320 V(I,I)=1.0
     :G=RV1(I)
     :L=I
1330 NEXT II
1340 'COMPUTE U IF MU="TRUE"
1350 IFMU$="TRUE"THEN1360ELSE1470
1360 MN=N
     :IFM<NTHENMN=M
```

```
1370 FORII=1TOMN
     :I=MN+1-II
     :L=I+1
     :G=W(I)
     :IFI=0THEN1390
1380 FORJ=LTON
     :U(I,J)=0
     :NEXTJ
1390 IFG=0THEN1430
1400 IFI=MNTHEN1420
1410 FORJ=LTON
     :S=0
     :FORK=LTOM
     :S=S+U(K,I)*U(K,J)
     :NEXTK
     :F=(S/U(I,I))/G
     :FORK=ITOM
     :U(K,J)=U(K,J)+F*U(K,I)
     :NEXTK
     :NEXTJ
1420 FORJ=ITOM
     :U(J,I)=U(J,I)/G
     :NEXTJ
     :GOTO1440
1430 FORJ=ITOM
     :U(J,I)=0
     :NEXTJ
1440 U(I,I)=U(I,I)+1
1450 NEXTII
1460 'DIAGONALIZATION OF THE BIDIAGONAL FOR
1470 FORKK=1TON
     :K1=N-KK
     :K=K1+1
     :ITS=0
1480 FORLL=1TOK
     :L1=K-LL
     :L=L1+1
     :IF(ABS(RV1(L))+AR)=ARTHEN1560
1490 IF(ABS(W(L1))+AR)=ARTHEN1510
1500 NEXTLL
1510 C=0
     :S=1
     :FORI=LTOK
     :F=S*RV1(I)
     :IF(ABS(F)+AR)=ARTHEN1560
1520 G=W(I)
     :H=SQR(F*F+G*G)
     :W(I)=H
     :C=G/H
     :S=-F/H
     :IFMU$="TRUE"THEN1530ELSE1540
1530 FORJ=1TOM
     :Y=U(J,L1)
     :Z=U(J,I)
     :U(J,L1)=Y*C+Z*S
     :U(J,I)=-Y*S+Z*C
     :NEXTJ
1540 NEXTI
1550 'TEST FOR CONVERGENCE
1560 Z=W(K)
```

```
    :IFL=KTHEN1670
1570 IFITS=30THEN1720
1580 ITS=ITS+1
    :X=W(L)
    :Y=W(K1)
    :G=RV1(K1)
    :H=RV1(K)
    :F=((Y-Z)*(Y+Z)+(G-H)*(G+H))/(2*H*Y)
    :G=SQR(F*F+1)
    :SS=SGN(F)
    :SF=SS*ABS(G)
    :F=((X-Z)*(X+Z)+H*(Y/(F+SF)-H))/X
    :C=1
    :S=1
1590 FORII=LTOK1
    :I=II+1
    :G=RV1(I)
    :Y=W(I)
    :H=S*G
    :G=C*G
    :Z=SQR(F*F+H*H)
    :RV1(II)=Z
    :C=F/Z
    :S=H/Z
    :F=X*C+G*S
    :G=-X*S+G*C
    :H=Y*S
    :Y=Y*C
    :IFMV$="TRUE"THEN1600ELSE1610
1600 FORJ=1TON
    :X=V(J,II)
    :Z=V(J,I)
    :V(J,II)=X*C+Z*S
    :V(J,I)=-X*S+Z*C
    :NEXTJ
1610 Z=SQR(F*F+H*H)
    :W(II)=Z
    :IFZ=0THEN1630
1620 C=F/Z
    :S=H/Z
1630 F=C*G+S*Y
    :X=-S*G+C*Y
    :IFMU$="TRUE"THEN1640ELSE1650
1640 FORJ=1TOM
    :Y=U(J,II)
    :Z=U(J,I)
    :U(J,II)=Y*C+Z*S
    :U(J,I)=-Y*S+Z*C
    :NEXTJ
1650 NEXTII
1660 RV1(L)=0
    :RV1(K)=F
    :W(K)=X
    :GOTO1480
1670 IFZ>=0THEN1700
1680 W(K)=-Z
    :IFMV$="TRUE"THEN1690ELSE1700
1690 FORJ=1TON
    :V(J,K)=-V(J,K)
    :NEXTJ
```

```
1700 NEXTKK
1710 GOTO1730
1720 IE=K
1730 RETURN
2000 '************************************
2010 'LINEAR REGRESSION CONTROL MODULE
2020 '//////////////////////
2030 CLS
     :PRINT@128,"ENTER VECTOR Y(R,C) IN X*B=Y  WHERE R=M & C=1."
     :GOSUB130
     :TSS=0
     :MSS=0
     :FORI=1TOR
     :Y(I,1)=A(I,1)
     :TSS=TSS+Y(I,1)*Y(I,1)
     :MSS=MSS+Y(I,1)
     :NEXTI
2040 CLS
     :PRINT@128,"ENTER MATRIX X(M,N) OF X*B=Y."
     :GOSUB130
2042 IFF$="XM"THEN2045ELSEF$="X"
2043 DD$="1"
     :GOSUB222
     :N=C1
2045 CLS
     :PRINT@458,"PLEASE BE PATIENT.  COMPUTATIONS IN PROGRESS."
     :GOSUB 1000
     :'SVD
2050 IF IE<>0THENCLS
     :PRINT@458,"ERROR RETURN FROM SVD"
     :STOP
2060 WI=10000
     :WM=0
     :FORJ=1TON
     :IFW(J)>WMTHENWM=W(J)
2065 IFW(J)<WITHENWI=W(J)
2070 B(J)=0
     :NEXTJ
     :CLS
     :PRINT@448,"NUMBER OF SIGNIFICANT FIGURES IN RAW DATA? --> ";
     :FL=-1
     :GOSUB15
     :S=VAL(IN$)
     :RE=0.1[S
     :TA=RE*WM
2080 RR=0
     :FORJ=1TON
     :IFW(J)<=TATHEN2100
2090 RR=RR+1
     :S=0
     :FORI=1TOM
     :S=S+U(I,J)*Y(I,1)
     :NEXTI
     :S=S/W(J)
     :FORI=1TON
     :B(I)=B(I)+S*V(I,J)
     :NEXTI
     :SV(J)=(1/W(J))L2
2100 NEXTJ
2102 IFRR<NTHENB(N+6)=-1ELSEB(N+6)=WI
```

```
104 B(N+4)=RE
   :B(N+5)=WM
   :B(N+7)=MSS/M
110 ESS=0
   :FORI=1TOM
   :RI=0
   :FORJ=1TON
   :R1=R1+B(J)*A(I,J)
   :NEXTJ
   :ESS=ESS+(R1-Y(I,1))[2
   :NEXTI
120 MSS=M*(MSS/M)[2
   :SE=SQR(ESS/(M-RR))
130 RSS=TSS-ESS
   :RMSS=RSS-MSS
   :TMSS=TSS-MSS
   :IFA(1,1)=1ANDA(INT(N/2),1)=1ANDA(N,1)=1THENMEAN$="TRUE"ELSEMEAN$="FALSE"
140 'DECISION BRANCHES FOR ANOVA TABLES
150 IFMEAN$="TRUE"THEN2170
160 RR=RR+1
   :FR=(RSS/RR)/(ESS/(M-RR))
   :DN=RR
   :DD=M-RR
   :GOSUB10000
   :A6=RR
   :A7=RSS
   :A8=RSS/RR
   :A9=FR
   :Z1=FB
   :Z2=M
   :Z3=TSS
   :GOTO2220
170 CLS
   :PRINT@448,"INCLUDE TERM FOR MEAN IN ANOVA? (Y/N) --> ";
   :FL=1
   :GOSUB15
   :IFIN$="Y"THENFM$="TRUE"ELSEFM$="FALSE"
180 IFFM$="FALSE"THEN2200
190 A1=1
   :A2=MSS
   :A3=MSS
   :FR=MSS/(ESS/(M-RR))
   :A4=FR
   :DN=1
   :DD=M-RR
   :GOSUB10000
   :A5=FB
   :A6=RR-1
   :A7=RMSS
   :A8=RMSS/(RR-1)
   :FR=A8/(ESS/(M-RR))
   :A9=FR
   :DN=RR-1
   :DD=M-RR
   :GOSUB10000
   :Z1=FB
   :Z2=M
   :Z3=TSS
   :GOTO2220
200 A6=RR-1
```

```
    :A7=RMSS
    :A8=RMSS/(RR-1)
    :A9=A8/(ESS/(M-RR))
    :FR=A9
    :DN=RR-1
    :DD=M-RR
    :GOSUB10000
    :Z1=FB
    :Z2=M-1
    :Z3=TMSS
2210 'ANOVA TABLE DISPLAY
2220 CLS
    :PRINT@10,"REGRESSION ANALYSIS OF VARIANCE TABLE"
2230 PRINT@128,"SOURCE";TAB(7)"DF";TAB(15)"SS";TAB(28)"MS";TAB(43)"F";TAB(50)"PR
BABILITY"
2240 PRINT@192,"-------------------------------------------------------------------"
2250 IFFM$="TRUE"THEN2260ELSE2270
2260 PRINT"MEAN";TAB(6)A1;TAB(12)A2;TAB(25)A3;TAB(40)A4;TAB(53);USING"#.####";A5
2270 PRINT"MODEL";TAB(6)A6;TAB(12)A7;TAB(25)A8;TAB(40)A9;TAB(53);USING"#.####";Z

2280 PRINT"ERROR";TAB(6)M-RR;TAB(12)ESS;TAB(25)ESS/(M-RR)
2290 PRINT"-------------------------------------------------------------"
2300 PRINT"TOTAL";TAB(6)Z2;TAB(12)Z3
2305 PRINT
    :PRINT"MEAN OF RESPONSE VARIABLE Y = "B(N+7)
2310 PRINT"STD.DEV. OF ERROR= "SQR(ESS/(M-RR));"  C.V. OF Y = ";USING"###.#";((S
R(ESS/(M-RR)))/B(N+7))*100
    :IFMEAN$="TRUE"THENR2=RMSS/TMSSELSER2=RSS/TSS
2312 PRINT"MULTIPLE CORRELATION COEFFICIENT (R**2) = ";R2
2345 A$=INKEY$
    :IFA$=""THEN2345
2350 GOSUB44000
2360 IFFM$="TRUE"THENB$="WITHOUT"ELSEB$="WITH"
2370 CLS
    :PRINT@448,"WANT TO VIEW THE ANOVA "B$" THE MEAN? (Y/N) --> ";
    :FL=1
    :GOSUB15
    :IFIN$="N"THEN2380ELSEIFIN$="Y"ANDB$="WITH"THENFM$="TRUE"
    :GOTO2190
    :ELSEFM$="FALSE"
    :GOTO2200
2380 IFMEAN$="TRUE"THENB(N+2)=1ELSEB(N+2)=2
2390 CLS
    :PRINT@448,"SAVING THE COEFFICIENT MATRIX "B" TO DISK."
2400 B(N+8)=N
    :B(N+1)=ESS/(M-RR)
    :B(N+3)=RR
    :FORI=1TON+8
    :A(I,1)=B(I)
    :NEXTI
    :N$(1)="1"
    :FF$="BN:1"
    :L$="BL:1"
    :F$="BM:1"
    :R=N+8
    :C=1
    :GOSUB225
2402 CLS
    :PRINT@448,"COMPUTING INVERSE(X'X) AND SAVING IT TO DISK."
2405 FORI=1TON
```

```
  :N$(I )=STR$(I )
  :NEXTI
  :'SET  COLUMN LABELS CORRECTLY
10 FORI=1TON
  :FORJ=1TON
  :U( I,J )=SV( I )*V( J,I )
  :NEXTJ,I
  :FORI=1TON
  :FORJ=1TON
  :A( I,J )=0
  :FORK=1TON
  :A( I,J )=A( I,J )+V( I,K )*U( K,J )
  :NEXTK,J,I
  :F$="XPXI"
  :DD$="1"
  :R=C1
  :C=C1
  :GOSUB222
15 CLS
  :PRINT@448,"CARE TO <S>EE OR <P>RINT THE X'X-1 MATRIX OR "
  :PRINT"<C>ONTINUE? --> ";
  :FL=1
  :GOSUB15
  :IFIN$="C"THEN2420ELSEIFIN$="S"THENGOSUB440ELSEIFIN$="P"THENGOSUB620
16 GOTO2415
20 RUN"GLM2/BAS"
30 END
000 '**************************************
010 'SUBROUTINE  FPROB
040 ' INPUT
  : FR=R RATIO  DN=NUMERATOR DF  DD=DENOMINATOR DF
050 'OUTPUT
  : FB= PROBABILITY OF F
060 '//////////////////////
0065 X#=1
  :IFFR<1THEN10080
0070 S#=DN
  :T#=DD
  :ZZ#=FR
  :GOTO10090
0080 S#=DD
  :T#=DN
  :ZZ#=1/FR
0090 J5=2/9/S#
  :K5=2/9/T#
  :Z#=K5*ZZ#[( 2/3 )+J5
  :GOSUB10500
  :Y#=ABS( ( 1-K5 )*ZZ#[( 1/3 )-1+J5 )/Z3#
  :IFT#<4THEN10110
0100 X#=.5/( 1+Y#*( .196854+Y#*( .115194+Y#*( .000344+Y#*.019527 ))))[4
  :X#=INT( X#*10000+.5 )/10000
  :GOTO10120
0110 Y#=Y#*( 1+.08*Y#[4/T#[3 )
  :GOTO10100
0120 IFF#>1THEN10140
0130 X#=1-X#
0140 FB=1-X#
0150 RETURN
0500 Z3#=SQR( Z# )
  :Z3#=( Z3#+Z#/Z3# )/2
```

```
    :Z3$=(Z3$+Z$/Z3$)/2
    :RETURN
40000 M=50
    :N=25
    :DIM N$(N),A(M,N),W(N),U(M,N),V(N,N),RV1(N),Y(M,1),B(N+8),SV(N)
40015 MV=-99.99
40020 RETURN
42000 CC=LEN(T$)
    :ZZ=INT(30-CC/2)
    :PRINT TAB(ZZ);T$
    :RETURN
    :'CENTERING ROUTINE
43000 END
44000 A$=INKEY$
    :IFA$=""THEN44000ELSEIFASC(A$)=64THENGOSUB670
44010 RETURN
```

APPENDIX II. Source code listing for program GLM2/BAS

```
10 CLEAR 500
    :TX=-1
    :GOTO1041
    :'GLM2/BAS  VERSION 10-29-80
13 '***************************************************
14 'ANSWER INPUT ROUTINE
15 P=(256*PEEK(16417)+PEEK(16416))-15359
    :IF ABS(FL)=1THEN16ELSE24
16 IN$=""
    :PRINT@P,CHR$(136);
    :LX=1
17 IN$=INKEY$
    :IFIN$=""THEN22
18 IFFL=-1 AND ASC(IN$)>47 AND ASC(IN$)<58 THEN 21
19 IF FL=1 AND ASC(IN$)>64 AND ASC(IN$)<91 THEN 21
20 GOTO 22
21 PRINT@P,IN$
    :RETURN
22 LX=LX+1
    :IFL<16THEN17
23 PRINT@P," ";
    :FORLX=1TO25
    :NEXT
    :GOTO16
24 PRINT@P, CHR$(136);
    :IN$=""
    :LX=ABS(FL)
    :GOSUB34
25 A$=INKEY$
    :IFA$=""THEN25
26 IFA$=CHR$(13)THENPRINTCHR$(15);
    :RETURN
27 IF A$=CHR$(8)THENIFIN$<>""THENPRINTA$;
    :PRINTCHR$(136);CHR$(24);
    :IN$=LEFT$(IN$,LEN(IN$)-1)
    :LX=LX+1
    :GOTO25
    :ELSEGOTO28
28 IFA$=CHR$(24)THENPRINTCHR$(29);
    :GOTO24
```

```
9 IF FL>0 AND ASC(A$)>31 AND ASC(A$)<91 THEN 32
0 IF FL<0 AND ASC(A$)>=45 AND ASC(A$)<58 THEN 32
1 GOTO 25
2 IF LX=0 THEN 25
3 PRINT A$;
   :IN$=IN$+A$
   :LX=LX-1
   :GOTO25
4 FOR IX=1TOLX-1
   :PRINT CHR$(136);
   :NEXT
   :FORJX=1TOLX
   :PRINT CHR$(24);
   :NEXT
   :RETURN
0 '************************************
2 'CHANGE VARIABLE NAMES
4 '//////////////
6 CLS
   :PRINT@448,"WHICH COLUMN'S NAME WILL BE CHANGED? --> ";
   :FL=-2
   :GOSUB15
   :XJ=VAL(IN$)
   :PRINT
   :PRINT"PLEASE ENTER NEW NAME --> ";
   :FL=8
   :GOSUB15
   :N$(XJ)=IN$
   :RETURN
00 '********************************************
10 'READ SEQUENTIAL DATA SET FROM DISK
20 '//////////////////
25 CLS
30 PRINT@448,"ENTER FILENAME OF DESIRED DATA SET --> ";
   :INPUT F$
35 FF$=F$+"N"
   :L$=F$+"L"
   :F$=F$+"M"
40 OPEN "I",1,FF$
   :INPUT#1,R,C
   :CLOSE1
   :'GET R,C VALUES
45 OPEN "I",1,L$
   :FORK=1TOC
   :INPUT#1,N$(K)
   :NEXTK
46 CLOSE
50 OPEN "I",1,F$
   :
60 FORI=1TOR
   :FORJ=1TOC
   :INPUT#1,A(I,J)
   :NEXTJ,I
170 CLOSE 1
80 RETURN
190 '************************************************
200 ' WRITE A SEQUENTIAL MATRIX TO DISK
210 '//////////////////////
220 CLS
   :PRINT@448,"ENTER FILENAME OF NEW DATA SET --> ";
   :INPUT F$
   :PRINT
   :PRINT"ENTER DISK DRIVE # WHERE DATA SHOULD BE SAVED --> ";
```

```
    :INPUT DD$
222 FF$=F$+"N:"+DD$
    :L$=F$+"L:"+DD$
    :F$=F$+"M:"+DD$
225 FOR JQ=1TOC
    :IF LEN(N$(JQ))=0 THEN N$(JQ)=STR$(JQ)
226 NEXT
230 OPEN "O",1,FF$
    :PRINT#1,R;C;
    :CLOSE1
240 OPEN "O",1,F$
    :
250 FORI=1TOR
    :FORJ=1TOC
    :PRINT#1,A(I,J);
    :NEXTJ,I
260 CLOSE 1
265 OPEN"O",1,L$
    :FORI=1TOC
    :PRINT#1,N$(I);",";
    :NEXT
    :CLOSE
270 RETURN
290 REM ***************************************************
295 REM                    SUBROUTINE INPUT
300 '1.   THIS SUB READS FROM THE KEYBOARD
305 '2.   MATRIX A IS LOADED AND CAN BE SAVED ON DISK
325 '6.   14-APR-79
335 REM ***************************************************
340 CLS
345 INPUT "PLEASE ENTER: NO. ROWS AND COLS (R,C).--> ";R,C
350 FL=8
    :PRINT
    :FOR J=1TOC
    :PRINT"ENTER THE NAME FOR VARIABLE ";J;" --> ";
    :GOSUB15
    :N$(J)=IN$
    :PRINT
    :NEXT
355 CLS
365 FOR I=1 TO R
370 PRINT "ROW ";I
375 FOR J=1 TO C
380 FL=-12
    :PRINT "PLEASE ENTER:  VALUE OF COLUMN ";J" --> ";
    :GOSUB 15
385 PRINT
390 A(I,J)=VAL(IN$)
395 NEXT J
400 NEXT I
430 RETURN
435 END
440 '*************************************************
445 '           SUBROUTINE VIDEO
450 '   DISPLAYS MATRIX A(R,C),13 ROWS BY 4 COLUMNS AT ONCE
455 ' USES ARROWS IN ALL DIRECTIONS TO SEE DIFFERENT PAGES
460 ' OF DATA.  "CLEAR" WILL TERMINATE DISPLAY
500 '***************************************************
510 CLS
    :IFR=0 OR C=0 THEN RETURN ELSE JJ=INT(C/4.1+1)
    :II=INT(R/13.1+1)
515 I=1
    :J=1
```

```
25      IF R-13*I>=0.0 THEN N=13 ELSE N=13+(R-13*I)
35      IF C-4*J>=0.0 THEN L=4 ELSE L=4+(C-4*J)
40 CLS
   :PRINT"COL:";
   :FOR KK=0TO(L-1)
   :PRINT TAB(14*KK+8) N$((KK+1)+4*(J-1));
45 NEXT KK
   :PRINT
50 PRINT"------------------------------------------------------"
55 FOR M=1 TO N
60 PRINT "R";M+13*(I-1);":";
65 FOR K=1 TO L
70 A=A(M+13*(I-1),K+4*(J-1))
75 PRINT TAB(14*(K-1)+8) A;
80 NEXT K
   :PRINT
85 NEXT M
86 A$=INKEY$
   :IFA$=""GOTO586
87 IF ASC(A$)=31THEN619ELSEIFASC(A$)=9THEN588ELSE590
88 IFJ+1>JJTHENJ=1ELSEJ=J+1
89 GOTO 525
90 IF ASC(A$)=8THEN591ELSE593
91 IF J-1<=0THENJ=JJ ELSE J=J-1
92 GOTO 525
93 IF ASC(A$)=10THEN594ELSE596
94 IF I+1>IITHENI=1ELSEI=I+1
95 GOTO 525
96 IF ASC(A$)=91THEN597ELSE599
97 IF I-1<=0THENI=IIELSEI=I-1
98 GOTO 525
99 IF ASC(A$)=64 THEN 600 ELSE 601
00 GOSUB 670
   :GOTO525
01 IF ASC(A$)=46 THEN GOSUB 50 ELSE 618
02 GOTO 525
18 GOTO586
19 RETURN
   :END
20 '**************************************************
22 'LINEPRINTER OUTPUT ROUTINE
23 IF R=0 OR C=0 THEN RETURN
24 AN$="DATA SET NAME --> "
   :CLS
   :PRINT@448,"PRESS <ENTER> WHEN PRINTER IS READY.";
   :INPUT AN
   :T$=LEFT$(F$,LEN(F$)-1)
   :T$=AN$+T$
   :GOSUB42000
   :LPRINT TAB(ZZ);T$
   :LPRINT " "
   :LPRINT " "
30 JJ=INT(C/4.1+1)
   :II=INT(R/200.1+1)
32 FORI=1TOII
34 IFR-200*I>=0.0THENN=200ELSEN=200+(R-200*I)
36 FORJ=1TOJJ
38 JFC-4*J>=0.0THENL=4ELSE L=4+(C-4*J)
40 LPRINT"COL:";
   :FORKK=0TO(L-1)
   :LPRINT TAB(14*KK+8) N$((KK+1)+4*(J-1));
42 NFXT KK
44 LPRINT" "
```

```
646 LPRINT"------------------------------------------------------------------"
648 FOR M=1TON
650 LPRINT "R";M+200*(I-1);":";
652 FOR K=1TO L
654 A=A(M+200*(I-1),K+4*(J-1))
656 LPRINT TAB(14*(K-1)+3) A;
658 NEXT K
660 LPRINT
662 NEXT M
664 LPRINT " "
    :LPRINT " "
    :LPRINT " "
666 NEXT J,I
668 RETURN
670 '*********************************
671 'SCREEN PRINT ROUTINE-  ACTIVATED BY PROGRAMMED "@" ASC(64)
672 '///////////////////////
673 IF PEEK(14312)<>63 THEN RETURN
674 LPRINT STRING$(64,"+")
675 FOR N= 15360 TO 16383 STEP 64
676 A$=" "
677 FOR Q=0TO63
680 Z=PEEK(N+Q)
    :IFZ>0ANDZ<27THENZ=Z+64ELSEIFZ<32THENZ=32
681 IFZ>=127 AND Z<=191 THEN Z=42
682 B$=CHR$(Z)
683 A$=A$+B$
684 NEXT Q
685 IF PEEK(14312)<>63THEN RETURN
686 LPRINT " "
    :LPRINT A$
687 NEXT N
688 LPRINT STRING$(64,"+")
689 FORN=1TO3
    :LPRINT "  "
    :NEXT
690 RETURN
1000 '****************************************
1010 'ANOVA TESTS OF HYPOTHESES
1020 'INPUT REQUIRED IS XPXI,B,Y,X FROM DISK
1030 '
1040 '////////////////////////
1041 CLS
    :PRINT@458,"READING THE X MATRIX FROM DISK."
1045 GOSUB 40000
    :'DIMENSIONING ROUTINE
1070 F$="X"
    :GOSUB135
    :'READ X FROM DISK
1075 FORI=1TON
    :X$(I)=N$(I)
    :NEXTI
    :'CREATE GUIDE FOR DESIGN MATRIX
1078 CLS
    :PRINT@458,"COMPUTING THE X'X MATRIX."
1080 FORI=1TOC
    :FORJ=1TOC
    :XPX(I,J)=0
    :FORK=1TOR
    :XPX(I,J)=XPX(I,J)+A(K,I)*A(K,J)
    :NEXTK,J,I
    :'COMPUTE XPX MATRIX-NOTE X'-->A(K,I)
1085 R=C
```

```
   :FORI=1TOC
   :FORJ=1TOC
   :A(I,J)=XPX(I,J)
   :NEXTJ,I
   :CLS
   :PRINT@448,"SAVING XPX MATRIX TO DISK."
   :F$="XPX"
   :D$="1"
   :GOSUB222
90 CLS
   :PRINT@448,"DISPLAY THE XPX MATRIX? (Y/N) --> ";
   :FL=1
   :GOSUB315
   :IFIN$="N"THEN1110
00 GOSUB3440
10 CLS
   :PRINT@448,"PRINT THE XPX MATRIX? (Y/N) --> ";
   :FL=1
   :GOSUB315
   :IFIN$="N"THEN1115ELSEF$="XPX "
   :GOSUB3620
15 CLS
   :PRINT@448,"COMPUTE TYPE I ESTIMABLE FUNCTIONS? (Y/N) --> ";
   :FL=1
   :GOSUB315
   :IFIN$="N"THEN1190
120 CLS
   :PRINT@448,"COMPUTING THE TYPE-I ESTIMABLE FUNCTIONS."
130 FORI=1TOC
   :FORJ=1TOC
   :A(I,J)=0
   :B(I,J)=0
   :NEXTJ,I
   :'SET A,B TO ZERO
140 FORJ=1TOC
   :A(1,J)=XPX(1,J)
   :B(1,J)=A(1,J)/A(1,1)
   :NEXTJ
150 FORK=2TOC
   :FORJ=KTOC
   :SUM=0
   :FORL=1TOK-1
   :SUM=SUM+A(L,K)*B(L,J)
   :NEXTL
   :A(K,J)=XPX(K,J)-SUM
   :IFABS(A(K,J))<1.0E-5THENA(K,J)=0
155 NEXTJ
   :FORJ=KTOC
   :IFA(K,K)<>0THENB(K,J)=A(K,J)/A(K,K)ELSE1158
156 NEXTJ
158 NEXTK
160 K=C
   :FORI=1TOC
   :FORJ=1TOC
   :A(I,J)=B(I,J)
   :NEXTJ,I
   :GOSUB3510
170 CLS
   :PRINT@448,"DO YOU WISH TO PRINT THE ESTIMABLE FUNCTIONS? (Y/N) --> ";
   :FL=1
   :GOSUB315
   :IFIN$="N"THEN1190
180 F$="ESTIMABLE FUNCTIONS "
   :GOSUB622
```

```
1190 RUN"GLM3/BAS"
40000 M=50
     :N=35
     :DIM N$(N),A(M,N),X(M,N),B(M,N),XPX(M,N),X$(N)
40015 MV=-99.99
40020 RETURN
42000 CC=LEN(T$)
     :ZZ=INT(30-CC/2)
     :PRINT TAB(ZZ);T$
     :RETURN
     :'CENTERING ROUTINE
43000 END
44000 A$=INKEY$
     :IFA$=""THEN44000ELSEIFASC(A$)=64THENGOSUB670
44010 RETURN
```

APPENDIX III. Source code listing for program GLM3/BAS

```
5 'CHANGED THE ORDER OF ON ERROR IN STATEMENT 9020-9051
10 CLEAR 500
    :TX=-1
    :GOTO1041
    :'GLM3/BAS VERSION 12-18-81
13 '*********************************************
14 'ANSWER INPUT ROUTINE
15 P=(256*PEEK(16417)+PEEK(16416))-15359
    :IF ABS(FL)=1THEN16ELSE24
16 IN$=""
    :PRINT@P,CHR$(136);
    :LX=1
17 IN$=INKEY$
    :IFIN$=""THEN22
18 IFFL=-1 AND ASC(IN$)>47 AND ASC(IN$)<58 THEN 21
19 IF FL=1 AND ASC(IN$)>64 AND ASC(IN$)<91 THEN 21
20 GOTO 22
21 PRINT@P,IN$
    :RETURN
22 LX=LX+1
    :IFLX<16THEN17
23 PRINT@P," ";
    :FORLX=1TO25
    :NEXT
    :GOTO16
24 PRINT@P, CHR$(136);
    :IN$=""
    :LX=ABS(FL)
    :GOSUB334
25 A$=INKEY$
    :IFA$=""THEN25
26 IFA$=CHR$(13)THENPRINTCHR$(15);
    :RETURN
27 IF A$=CHR$(8)THENIFIN$<>""THENPRINTA$;
    :PRINTCHR$(136);CHR$(24);
    :IN$=LEFT$(IN$,LEN(IN$)-1)
    :LX=LX+1
    :GOTO25
    :ELSEGOTO28
28 IFA$=CHR$(24)THENPRINTCHR$(29);
    :GOTO24
```

```
9 IF FL>0 AND ASC(A$)>31 AND ASC(A$)<91 THEN 32
0 IF FL<0 AND ASC(A$)>=45 AND ASC(A$)<58 THEN 32
1 GOTO 25
2 IF LX=0 THEN 25
3 PRINT A$;
   :IN$=IN$+A$
   :LX=LX-1
   :GOTO25
4 FOR IX=1TOLX-1
   :PRINT CHR$(136);
   :NEXT
   :FORJX=1TOLX
   :PRINT CHR$(24);
   :NEXT
   :RETURN
00 '***************************************
10 'READ SEQUENTIAL DATA SET FROM DISK
20 '////////////////////////
25 CLS
30 PRINT@448,"ENTER FILENAME OF DESIRED DATA SET --> ";
   :INPUT F$
35 FF$=F$+"N"
   :L$=F$+"L"
   :F$=F$+"M"
40 OPEN "I",1,FF$
   :INPUT#1,R,C
   :CLOSE1
   :'GET R,C VALUES
45 OPEN "I",1,L$
   :FORK=1TOC
   :INPUT#1,N$(K)
   :NEXTK
46 CLOSE
50 OPEN "I",1,F$
   :
60 FORI=1TOR
   :FORJ=1TOC
   :INPUT#1,A(I,J)
   :NEXTJ,I
170 CLOSE 1
180 RETURN
190 '*******************************************
200 ' WRITE A SEQUENTIAL MATRIX TO DISK
210 '//////////////////////
220 CLS
   :PRINT@448,"ENTER FILENAME OF NEW DATA SET --> ";
   :INPUT F$
   :PRINT
   :PRINT"ENTER DISK DRIVE # WHERE DATA SHOULD BE SAVED --> ";
   :INPUT DD$
222 FF$=F$+"N:"+DD$
   :L$=F$+"L:"+DD$
   :F$=F$+"M:"+DD$
225 FOR JQ=1TOC
   :IF LEN(N$(JQ))=0 THEN N$(JQ)=STR$(JQ)
226 NEXT
230 OPEN "O",1,FF$
   :PRINT#1,R;C;
   :CLOSE1
240 OPEN "O",1,F$
   :
250 FORI=1TOR
   :FORJ=1TOC
   :PRINT#1,A(I,J);
```

```
    :NEXTJ,I
260 CLOSE 1
265 OPEN"O",1,L$
    :FORI=1TOC
    :PRINT#1,N$(I);",";
    :NEXT
    :CLOSE
270 RETURN
920 GOTO 735
1000  ******************************************
1010 'ANOVA TESTS OF HYPOTHESES
1020 'INPUT REQUIRED IS XPXI,B,Y,X FROM DISK
1030 '
1040 '//////////////////////
1041 CLS
    :PRINT@458,"READING THE G AND XPX MATRICES FROM DISK."
1045 GOSUB 40000
    :'DIMENSIONING ROUTINE
1050 F$="XPXI"
    :GOSUB135
    :'READ XPXI FROM DISK
1060 FORI=1TOR
    :FORJ=1TOC
    :G(I,J)=A(I,J)
    :NEXTJ,I
1070 F$="XPX"
    :GOSUB135
    :'READ X FROM DISK
1075 N=C
    :C8=C
    :FORI=1TON
    :X$(I)=N$(I)
    :NEXTI
    :'CREATE GUIDE FOR DESIGN MATRIX
1085 CLS
    :PRINT@458,"COMPUTING THE H MATRIX."
1090 FORI=1TOC
    :FORJ=1TOC
    :H(I,J)=0
    :FORK=1TOC
    :H(I,J)=H(I,J)+G(I,K)*A(K,J)
    :NEXTK,J,I
    :'COMPUTE THE H MATRIX
1095 CLS
    :PRINT@458,"READING THE B MATRIX FROM DISK."
1100 F$="B"
    :GOSUB135
    :N=A(R,1)
    :FORI=1TON
    :B(I)=A(I,1)
    :NEXTI
    :SIG=A(N+1,1)
    :'READ THE B MATRIX FROM DISK
1110 CLS
    :PRINT"CREATE THE TEST MATRIX (K) OF  K'B=M"
    :PRINT
    :J=1
1120 N=C8
    :FORI=1TON
    :PRINT"ENTER THE DESIGN VALUE FOR "X$(I)" --> ";
    :FL=-8
    :GOSUB15
    :K(I,J)=VAL(IN$)
    :PRINT
```

```
   :NEXTI
   :PRINT
   :PRINT"ANOTHER DESIGN COLUMN? (Y/N) --> ";
   :FL=1
   :GOSUB15
130 IFIN$="Y"THEN1140ELSE1160
140 J=J+1
   :IFJ<=NTHEN1120ELSEPRINT"SORRY. NO MORE DEGREES OF FREEDOM REMAINING."
150 A$=INKEY$
   :IFA$=""THEN1150
160 JJ=J
   :CLS
   :PRINT"CREATE THE MATRIX M OF K'B=M"
   :PRINT
165 FORI=1TON
   :M(I)=0
   :NEXTI
   :'INITIATE M AS THE NULL VECTOR
170 PRINT"IS M THE NULL VECTOR? (Y/N) --> ";
   :FL=1
   :GOSUB15
   :IFIN$="N"THEN1180ELSE1190
180 FORI=1TOJJ
   :PRINT"ENTER M VALUE FOR CONTRAST # "I" --> ";
   :FL=-4
   :GOSUB15
   :M(I)=VAL(IN$)
   :PRINT
   :NEXTI
190 GOSUB6000
   :'CHECK FOR ESTIMABILITY
195 IFTX=-1THEN1110
200 CLS
   :PRINT@448,"PLEASE BE PATIENT.  COMPUTING SUMS OF SQUARES."
205 FORI=1TON
   :KB(I)=0
   :NEXTI
1210 FORJ=1TOJJ
   :FORI=1TON
   :KB(J)=KB(J)+K(I,J)*B(I)
   :NEXTI,J
1220 FORI=1TOJJ
   :KB(I)=KB(I)-M(I)
   :NEXTI
   :'K'B-M NOW IN KB(.)
1230 FORI=1TON
   :FORJ=1TOJJ
   :T(I,J)=0
   :FORK=1TON
   :T(I,J)=T(I,J)+G(I,K)*K(K,J)
   :NEXTK,J,I
   :FORI=1TOJJ
   :FORJ=1TOJJ
   :A(I,J)=0
   :FORK=1TON
   :A(I,J)=A(I,J)+K(K,I)*T(K,J)
   :NEXTK,J,I
   :'  K'GK COMPUTED AS A
1235 FORI=1TON
   :FORJ=1TON
   :IFABS(A(I,J))<1E-6THENA(I,J)=0
1236 NEXTJ,I
1240 'BD$="1"
   :F$="KPGK"
```

```
    :N=JJ
    :C=JJ
    :FORI=1TOJJ
    :N$(I)=STR$(I)
    :NEXTI
    :GOSUB222
    : SAVE K'GK ON DISK #1
1250 IFJJ=1THENA(1,1)=1/A(1,1)
    :GOTO1260
    :ELSEGOSUB8500
    :' IF JJ=1 THEN JUST INVERT, ELSE CALCULATE THE INVERSE
1260 FORI=1TOJJ
    :J(I)=0
    :FORJ=1TOJJ
    :J(I)=J(I)+A(I,J)*KB(J)
    :NEXTJ,I
    :Q=0
    :FORI=1TOJJ
    :Q=Q+KB(I)*J(I)
    :NEXTI
    :' CALCULATION OF Q
1280 CLS
    :PRINT@448,"DF= "JJ"     SS(HO)= "Q"      MS(HO)= "Q/JJ
    :PRINT
    :PRINT"TEST ANOTHER HYPOTHESIS? (Y/N) --> ";
    :FL=1
    :GOSUB15
    :IFIN$="N"THEN1290ELSE1110
1290 CLS
    :PRINT@448,"RUN ANOTHER PROBLEM? (Y/N) --> ";
    :FL=1
    :GOSUB15
    :IFIN$="Y"THENRUN"GLM1/BAS"ELSEEND
6000 '*******************************************
6010 'ROUTINE TO CHECK FOR ESTIMABILITY OF KB=M
6020 ' TEST IS
    : K'H=K'
6030 '//////////////////////////
6035 CLS
    :PRINT@458,"CHECKING FOR ESTIMABILITY."
6040 FORI=1TOJJ
    :FORJ=1TON
    :KH=0
    :FORK=1TON
    :KH=KH+K(K,I)*H(K,J)
    :NEXTK
    :IFABS(KH)<1E-5THENKH=0
6050 IF ABS(K(J,I))>(ABS(KH)+1E-3)ORABS(K(J,I))<(ABS(KH)-1E-3)THEN6080
6060 NEXTJ,I
6070 TX=1
    :RETURN
6080 CLS
    :PRINT@448,"THE FUNCTIONS IN THE K MATRIX ARE NOT ESTIMABLE.  PLEASE TRY AGAI
N."
    :PRINT"<ENTER> TO CONTINUE."
6090 A$=INKEY$
    :IFA$=""THEN6090
6100 TX=-1
    :RETURN
8500 REM ***********************************************
8510 REM        SUBROUTINE FOR MATRIX INVERSION
8520 '   EMPLOYS GAUSS-JORDAN ELIMINATION WITH COLUMN
8530 '   SHIFTING TO MAXIMIZE PIVOT ELEMENTS.
8540 '
```

```
'  INPUTS
:
'    A(I,I) MUST BE A SQUARE, NONSINGULAR MATRIX
'    N = ORDER OF MATRIX
'
'  OUTPUTS
:
'    A(N,N) CONTAINS THE INVERSE
'    DETM  CONTAINS THE DETERMINANT
'    DTNRM  CONTAINS MAGNITUDE OF DET/EUCLIDIAN NORM
'
'  NOTE
: THIS ROUTINE TESTS FOR A SINGULAR MATRIX
'          AND PRINTS AN ERROR OUT IF A(N,N) IS SINGULAR
REM ***********************************************
NN=N
N=JJ
PD=1.0
FOR L=1 TO N
DD=0
FOR K=1 TO N
DD=DD+A(L,K)*A(L,K)
NEXT K
DD=SQR(DD)
PD=PD*DD
NEXT L
DETM=1.0
FOR L=1 TO N
J(L+20)=L
NEXT L
FOR L=1 TO N
CC=0.0
M=L
FOR K=L TO N
IF((ABS(CC)-ABS(A(L,K))) > 0.0) GOTO 8910
M=K
CC=A(L,K)
NEXT K
IF L=M GOTO 9010
K=J(M+20)
J(M+20)=J(L+20)
J(L+20)=K
FOR K=1 TO N
S=A(K,L)
A(K,L)=A(K,M)
A(K,M)=S
NEXT K
A(L,L)=1.0
DETM=DETM*CC
ON ERROR GOTO 9380
FOR M=1 TO N
PRINT A(L,M),L,M,CC
A(L,M)=A(L,M)/CC
NEXT M
ON ERROR GOTO 0
FOR M=1 TO N
IF L=M GOTO 9140
CC=A(M,L)
IF CC=0.0 GOTO 9140
A(M,L)=0.0
FOR K=1 TO N
A(M,K)=A(M,K)-CC*A(L,K)
NEXT K
```

```
9140 NEXT M
9150 NEXT L
9160 FOR L=1 TO N
9170 IF J(L+20) = L GOTO  9290
9180 M=L
9190 M=M+1
9200 IF J(M+20) = L GOTO 9220
9210 IF N > M GOTO 9190
9220 J(M+20)=J(L+20)
9230 FOR K=1 TO N
9240 CC=A(L,K)
9250 A(L,K)=A(M,K)
9260 A(M,K)=CC
9270 NEXT K
9280 J(L+20)=L
9290 NEXT L
9300 DETM=ABS(DETM)
9310 DTNRM=DETM/PD
9311 CLS
9312 IF DETM=0.0 GOTO 9370
9320 N=NN
    :RETURN
    :'RETURN N TO ITS ORIGINAL VALUE
9324 END
9370 '       ROUTINE TO HANDLE A SINGULAR MATRIX
9380 CLS
9390 PRINT" AM SORRY.  MATRIX A  IS SINGULAR."
9400 PRINT"A SINGULAR MATRIX HAS NO UNIQUE INVERSE."
9410 PRINT"IF YOU MUST GET AN INVERSE,OBTAIN A PROGRAM"
9420 PRINT"WHICH CAN CALCULATE THE PSEUDO-INVERSE OF A"
9430 PRINT"SINGULAR MATRIX.  "
9450 END
10000 CLS
    :PRINT@448,"MATRICES B, Y, X AND (X'X)-1 WILL NOW BE READ FROM DISK."
    :F$="B"
    :GOSUB135
    :FORI=1TOR
    :B(I)=A(I,1)
    :NEXTI
    :N=B(R)
    :F$="Y"
    :GOSUB135
    :FORI=1TOR
    :FORJ=1TOC
    :Y(I,J)=A(I,J)
    :NEXTJ,I
    :M=R
10010 FORI=1TO6
    :YN$(I)=N$(I)
    :NEXTI
    :F$="XPXI"
    :GOSUB135
    :FORI=1TON
    :FORJ=1TON
    :XI(I,J)=A(I,J)
    :NEXTJ,I
    :F$="X"
    :GOSUB135
    :FM$="TRUE"
    :RETURN
```

```
000 M=35
  :N=35
  :DIM N$(N),A(M,N),B(N),Y(M,1),G(N,N),XPX(N,N),H(N,N),J(N+20),X$(N),T(N,N),K(2
20),M(N),KB(N)
015 MV=-99.99
  :FM$="FALSE"
020 RETURN
000 CC=LEN(T$)
  :ZZ=INT(30-CC/2)
  :PRINT TAB(ZZ);T$
  :RETURN
  :'CENTERING ROUTINE
000 END
```

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Rauscher, Harald M.

The microcomputer scientific software series 3: general linear model—analysis of variance. Gen. Tech. Rep. NC-86. St. Paul, MN: North Central Forest Experiment Station; 1983. 35 p.

A BASIC language set of programs, designed for use on microcomputers,is presented. This set of programs will perform the analysis of variance for any statistical model describing either balanced or unbalanced designs. The program computes and displays the degrees of freedom, Type I sum of squares, and the mean square for the overall model, the error, and each factor in the model.

KEY WORDS: Balanced designs, BASIC, unbalanced designs, TRS-80, singular value decomposition.

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